

PRESSING NEEDS IN AERONAUTICS RESEARCH

REPORT NS454T1

Earl R. Wingrove III

Shahab Hasan

Lauren M. Nolte



JUNE 2005

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Executive Summary

The National Research Council (NRC), in *Securing the Future of U.S. Air Transportation: A System in Peril*, recommended that the U.S. government create a comprehensive, widely accepted long-term vision and a coherent set of requirements for all federal agencies with a major stake in the air transportation system. As the nation's leading aeronautics research organization, NASA features prominently in the NRC report, and many of its findings and recommendations directly affect NASA. In addition to that report, other external reviews dating back to 1997 have addressed issues relevant to NASA aeronautics research.

NASA asked LMI to conduct an independent review of 11 recent reports to identify findings related to NASA's recent role and activities in aeronautics research. We also identified recommendations that could affect NASA's future leadership in aeronautical research.

In general, the 11 reports we analyzed consistently emphasize the importance of U.S. air transportation to our national interests. Reduced technological advantage and declining economic strength are among the problems with high-priority recommendations attached to them. Most of the reports also stress the importance of federal support for aeronautics research, in both financial and leadership terms.

Inadequate research coordination is the most severe problem in terms of frequency and urgency of the recommendations. According to most of the reports, the complexity of the air transportation system and aeronautics technology requires some kind of process to coordinate government-wide research. This capability implies clear national objectives to frame and guide research requirements as well as a body with the authority to oversee interactions among multiple actors.

Another central theme in these reports is helping the aviation industry overcome barriers to progress. The primary barriers include limited capacity of the air transportation system, constraints posed by noise and emissions, and limited transition of new technologies from government research and development programs.

Specific findings and recommendations in the 11 reports can be summarized as follows:

- ◆ It is in the national interest to maintain global leadership in aerospace in an increasingly competitive environment, and to that end, the United States should invest in aeronautics research and development. The U.S. government should increase its investment in aeronautics infrastructure, workforce, and NASA-sponsored research. The United States also must engage in international issues related to aeronautics.
- ◆ The U.S. government needs to provide leadership and a vision to set national goals for aeronautics and air transportation. Aeronautics leadership and research require a coordinated effort involving NASA, other government agencies, industry, and academia.
- ◆ A transformational, forward-looking, centrally directed research and implementation effort is needed to meet the projected demand for air transportation in the future.
- ◆ NASA should develop partnerships and mechanisms to encourage and accelerate the transition of technology into products. The government should also lead the development of future operational concepts in partnership with other stakeholders.
- ◆ The principal focus for safety should be on reducing the rate of accidents by a factor of five; this will require a focused strategic plan, more effective safety risk management programs, and a global approach.
- ◆ The federal government must lead the fight against security threats, commit greater resources to improving aviation security, and work cooperatively with the private sector and local authorities.
- ◆ NASA should put a priority on airframe and propulsion technologies to improve performance, reduce fuel consumption, and foster innovative vehicle concepts. NASA should also enhance its capabilities for vehicle design, test, and flight evaluation.

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Chapter 1

Introduction

Aviation in the 20th century is one of America's great success stories. NASA's Aeronautics Blueprint states:

Over the last century, aviation has evolved to become an integral part of our economy, a cornerstone of our national defense, and an essential component of our way of life. Aviation generates more than \$1 trillion of economic activity in the United States every year. Military aviation forms the backbone of the U.S. security strategy.¹

The air transportation sector is undeniably important to the U.S. economy and the standard of living of our citizens. As pointed out by a recent National Research Council (NRC) study:

Current U.S. visions for civil aviation correctly point out the importance of civil aviation to the national economy and overall standard of living. People want to travel quickly and comfortably. Businesses and their customers want products delivered overnight. Per capita use of aviation is higher in the United States than any other country in the world, and non-business travel accounts for more than 50 percent of passenger air travel. The availability of quick and affordable options for long-distance travel increases demand. That will probably always be the case. To the extent that air transportation can continue to satisfy these universal human desires safely, reliably, and affordably, air transportation will remain relevant.²

This study also noted that the success of U.S. aviation has created challenges for the future:

The air transportation system is changing and will continue to change. Over the long term, however, it will be difficult for the air transportation system to change rapidly enough to meet changing requirements related to capacity, environmental effects, consumer satisfaction, safety, and security, while meeting ongoing requirements for the economic viability of service providers.³

Meeting the broad set of aeronautics challenges described above has been the focus of several reports in recent years. Set against the backdrop of an eroding national leadership in aeronautics technology, these reports call for renewed action

¹ NASA, *The NASA Aeronautics Blueprint: A National Imperative for Aviation*, 2002, p. 3.

² National Research Council, *Securing the Future of U.S. Air Transportation: A System in Peril*, 2003, p. 8.

³ *Ibid.*, p. 13.

and commitment to aeronautics on the part of the government. Although some of these studies have been sponsored by NASA and others have been conducted at the request of other organizations, they all take a close look at the importance of air transportation to our national interests, what the air transportation system and the aeronautics industry need most, and how NASA aeronautics research can best address these concerns.

NASA clearly recognizes that its job extends beyond basic exploratory research and includes helping the country “address its urgent national needs.”⁴ Although NASA has been taking steps to maintain U.S. leadership in aeronautics technology, NASA’s Aeronautics Technology Theme (now the Aeronautics Research Mission Directorate, or ARMD) asked LMI to review 11 recent external reports and determine whether the NASA aeronautics research program is addressing the reports’ recommendations. The objective of this effort is to highlight areas where NASA is effectively responding to national aeronautics needs and also to identify areas where NASA could improve its responsiveness.

Table 1-1 lists the 11 reports that LMI reviewed; Appendix A contains the title pages and executive summaries from the reports.

Table 1-1. Reports Reviewed by LMI

Report title (full)	Report title (abbreviated)	Year	Author	Objective
Aerospace Research and Development 5-Year R&D Plan	5-Year R&D Plan	2004	Aerospace Industries Association	Propose 5-year research and development objectives for NASA, the Federal Aviation Administration (FAA), and the Department of Defense (DoD)
Securing the Future of U.S. Air Transportation: A System in Peril	System in Peril	2003	National Research Council, Committee on Aeronautics Research and Technology for Vision 2050	Identify the extent to which expected advances in key technologies could achieve the aviation vision in 2025 and 2050, as well as identify key technological goals that will not be met by continued evolution of existing programs; identify critical initiatives needed to reach key goals, and determine if major changes in national aeronautics programs would make it easier to achieve the key goals
Persistent and Critical Issues in the Nation’s Aviation and Aeronautics Enterprise	Persistent and Critical Issues	2003	American Society of Mechanical Engineers, Aerospace Division	Provide the engineering community’s perspective on prioritizing technologies critical to the long-term health of the nation’s civil and military aviation and aeronautics technology enterprise (at the request of the Office of Science and Technology Policy)

⁴ NASA, *NASA 2003 Strategic Plan*, 2003, p. 2.

Table 1-1. Reports Reviewed by LMI

Report title (full)	Report title (abbreviated)	Year	Author	Objective
For Greener Skies: Reducing Environmental Impacts of Aviation	For Greener Skies	2002	National Research Council, Committee on Aeronautics Research and Technology for Environmental Compatibility	Assess whether existing research policies and programs are likely to foster the technological improvements needed to ensure that environmental constraints do not become a significant barrier to growth of the aviation sector, and recommend a framework for government research policies and programs
Aeronautics Research and Technology for 2050: Assessing Visions and Goals	Assessing Visions and Goals	2002	National Research Council, Committee on Aeronautics Research and Technology for Vision 2050	Conduct a comparative assessment of the long-term visions and goals for U.S. civil aviation
Commission on the Future of the U.S. Aerospace Industry Final Report	President's Commission Report	2002	Commission on the Future of the U.S. Aerospace Industry (established by Congress in P.L. 106-398, the FY 2001 National Defense Authorization Act)	Assess health of the aerospace industry, evaluate the future importance of the domestic aerospace industry for the economic and national security of the United States, and identify actions that the United States needs to take to ensure its health in the future
Future Flight: A Review of the Small Aircraft Transportation System (SATS) Concept	Future Flight (SATS)	2002	National Research Council, Transportation Research Board, Committee for a Study of Public-Sector Requirements for a Small Aircraft Transportation System	Review the validity of the assumptions about future travel demand and transportation capacity challenges and consider whether the benefits of SATS warrant accelerated institutional changes and investment
Commercial Supersonic Technology: The Way Ahead	Commercial Supersonic Technology	2001	National Research Council, Committee on Breakthrough Technology for Commercial Supersonic Aircraft	Identify breakthrough technologies for overcoming key barriers to the development of an environmentally acceptable and economically viable commercial supersonic aircraft, focusing on areas where NASA-supported research could make a difference in the next 25 years
Recent Trends in U.S. Aeronautics Research and Technology	Recent Trends	1999	National Research Council, Committee on Strategic Assessment of U.S. Aeronautics	Assess recent trends in the U.S. aeronautics research and technology program
Avoiding Aviation Gridlock and Reducing the Accident Rate: A Consensus for Change	Avoiding Aviation Gridlock	1997	National Civil Aviation Review Commission (established by Congress)	Develop two reports, one on funding the nation's civil aviation programs and one on aviation safety
White House Commission on Aviation Safety and Security: Final Report to President Clinton	Commission on Aviation Safety and Security	1997	White House Commission on Aviation Safety and Security (established by Executive Order 13015)	Study matters involving aviation safety and security, including air traffic control, and develop a strategy to improve aviation safety and security

During the first phase of the review, LMI identified findings related to NASA's recent role and activities in aeronautics research. We also identified recommendations that could affect NASA's future leadership in aeronautical research. In the second phase, LMI reviewed current and planned NASA research programs and described how those program activities relate to findings and recommendations in the external reviews. In the final phase of the study, LMI identified gaps in NASA's plans and programming that may need to be addressed in future planning efforts.

This report conveys the results of the first phase of our review. In the next chapter, we summarize the problems raised and recommendations made by the 11 reports. The appendixes contain additional detail.

Chapter 2

Problems Identified

For the most part, the 11 reports we reviewed varied in their central objective and theme. Although they made many of the same types of recommendations, each report had a unique set of recommended actions. After reviewing the 11 reports, LMI developed a taxonomy of 35 problems that the reports identified. We grouped these problems into five major problem areas:

- ◆ Threats to our nation
- ◆ Barriers to progress—problems in our government
- ◆ Barriers to progress—problems in the aviation industry
- ◆ Research and technology needs—air transportation system
- ◆ Research and technology needs—air vehicles.

The 11 reports we reviewed consistently emphasize the importance of U.S. aviation to our national interests. Reduced U.S. technological advantage and leadership and declining U.S. market share and economic strength are among the problems with high-priority recommendations attached to them.

The reports also highlight the barriers that must be overcome to reduce these threats to our national interests. In terms of governmental barriers, most of the reports stress the importance of federal support for aeronautics research, in both financial and leadership terms. Inadequate government-wide coordination of aeronautics research is one of the most severe problems in terms of frequency and urgency of the recommendations.

According to most of the reports, the complexity of the air transportation system and aeronautics technology requires some kind of process to coordinate government-wide research. This capability requires clear national objectives to frame and guide research requirements as well as a body with the authority to oversee interactions among multiple actors. It is the hope that these governance and oversight efforts will help focus research in the areas with the greatest need.

The primary barriers in the aviation industry include the limited capacity of the air transportation system, constraints posed by noise and emissions, safety hazards, and limited adoption and transition of new technologies from government R&D programs to industry.

Last, there remain a series of specific research and technology (R&T) needs keyed to the air transportation system and air vehicles. The most important of these are modeling and simulation, analytical and prediction tools, human factors, airframe configuration, propulsion systems, and alternative power sources.

Table 2-1 lists the 35 problems, organized by major problem area, and shows which reports raised the problems and the level of emphasis the recommendations received. Appendix B provides more insight by listing summaries of the findings and recommendations offered by each report.

Table 2-1. Recommendations by Report and Problem Category

Problem	5-Year R&D Plan	System in Peril	Persistent and Critical Issues	For Greener Skies	Assessing Visions and Goals	President's Commission Report	Future Flight (SATS)	Commercial Supersonic Technology	Recent Trends	Avoiding Aviation Gridlock	Commission on Aviation Safety and Security
Threats to our nation											
Reduced U.S. technological advantage and leadership											
Declining U.S. market share and economic strength											
Negative environmental effects											
National security risks											
Barriers to progress—problems in our government											
Lack of national leadership											
Lack of clear objectives, strategy, and guidance											
Inadequate processes for developing goals and budgeting for, managing, and evaluating programs											
Lack of well-formulated, realistic goals and timelines											
Lack of needs, and feasibility, analysis to guide definition of R&T programs											
Misdirected and inefficient use of resources											
Inadequate government-wide coordination of aeronautics R&T											
Lack of collaboration with other stakeholders											
Weakening commitment to aeronautics R&T investment											

Table 2-1. Recommendations by Report and Problem Category

Problem	5-Year R&D Plan	System in Peril	Persistent and Critical Issues	For Greener Skies	Assessing Visions and Goals	President's Commission Report	Future Flight (SATS)	Commercial Supersonic Technology	Recent Trends	Avoiding Aviation Gridlock	Commission on Aviation Safety and Security
Barriers to progress—problems in the aviation industry											
Limited capacity of current air transportation system and inadequate performance											
Constraints resulting from negative impact of emissions											
Constraints resulting from negative impact of noise											
Safety hazards											
Declining RDT&E infrastructure											
Declining workforce											
Inadequate transition of government aeronautics technology to industry											
Research and technology needs—air transportation system											
Distributed communication networks and decision-support tools											
Environmental impact of aviation											
Human factors and human-automation interaction											
Modeling and simulation and analytical and prediction tools											
Non-technological factors											
Research and technology needs—air vehicles											
Aerodynamics											
Propulsion systems											
Alternative power sources								X ^a			
Cockpit displays/avionics											
Composite materials											

Table 2-1. Recommendations by Report and Problem Category

Problem	5-Year R&D Plan	System in Peril	Persistent and Critical Issues	For Greener Skies	Assessing Visions and Goals	President's Commission Report	Future Flight (SATS)	Commercial Supersonic Technology	Recent Trends	Avoiding Aviation Gridlock	Commission on Aviation Safety and Security
Flight control systems and software											
Nanotechnology											
Systems engineering, and design and integration tools											
Aging of nonstructural components											
Applications to specific vehicles											

Key:

	= Higher priority recommendation
	= Lower priority recommendation
	= Not addressed

^a Recommendation against action in this research area.

THREATS TO OUR NATION

Threats to our nation include problems related to U.S. leadership in aeronautics technology and in the global marketplace, as well as the national security needs associated with aeronautics technology development. Nearly all of the reports recognize the declining U.S. share of the aeronautics market and the potential decline in U.S. technological advantage as major problems that go hand in hand. First, several studies stress the importance of air transportation to our national interests, including economic prosperity and national security. *President's Commission Report* summarizes it well:¹

The integral role aerospace plays in our economy, our security, our mobility, and our values makes global leadership in aviation and space a national imperative.²

The American Society of Mechanical Engineers echoes these concerns. Its findings state that “the support provided by the federal government to civil aeronautics research is not commensurate with the importance of air transportation in the

¹ For the sake of brevity, we use the short titles of the 11 reports. See Chapter 1 for the list and corresponding full titles.

² *President's Commission Report*, p. 1-7.

nation's economy and security.”³ According to some published estimates, the total economic impact of civil aviation in 2000 exceeded \$900 billion and 11 million jobs, about 9 percent of the total U.S. gross domestic product.⁴ “Control of the skies” is also crucial to U.S. national security, and aeronautical capability “will be the key to our ability to wage future wars.”⁵ Airborne reconnaissance, disruption of enemy infrastructure, quick response to faraway conflicts, and rapid search and rescue are all essential capabilities of air power and national defense.

According to most of the reports, U.S. leadership is at risk. Several reports point out that the aeronautics segment of the economy is becoming less competitive in the global arena and losing market share to European companies. *Recent Trends* warns that if this continues, it will lead to the “demise of aeronautics as a viable enterprise.”⁶ Because aeronautics is such an R&T-intensive industry, absent a strong national aeronautics R&T program, “the United States is likely to become less competitive in aeronautics relative to countries with stronger programs.”⁷ Ominously, “as the two traditional sources of support for aeronautics R&T, industry and government, have been falling in the United States, government support for aerospace R&T in the European Union has been growing.”⁸

President's Commission Report proposes a variety of ways to enhance U.S. competitiveness in the global marketplace. The report recommends reforming U.S. and multilateral regulations and policies to enable freer movement of products and capital across international borders. It also recommends promoting a new business model for the U.S. aerospace industry by investing in the industry and developing policies that stimulate the flow of capital into these companies.

Although most of the reports stressed U.S. economic and technological leadership, the recommendations in *Recent Trends* cut across all of the national problem areas. In particular, this report called on the federal government to “analyze the national security implications of reduced aeronautics research and technology funding.”⁹

BARRIERS TO PROGRESS—PROBLEMS IN OUR GOVERNMENT

Lack of strong national leadership, clear objectives, and a process to develop aeronautics program goals and activities are important problems cited in *System in Peril*, *President's Commission Report*, and *For Greener Skies*. All three reports

³ *Persistent and Critical Issues*, p. 5.

⁴ *Persistent and Critical Issues*, p. 8.

⁵ *Recent Trends*, p. 17.

⁶ *Recent Trends*, p. 1.

⁷ *Recent Trends*, p. 5.

⁸ *Recent Trends*, p. 5.

⁹ *Recent Trends*, p. 15.

recommend that the federal government make air transportation a strong priority and establish a national vision for aeronautics. Each of the three reports describes a different process by which the federal government and NASA should develop and manage aeronautics activities.

System in Peril recommends that improving the long-term performance of the air transportation system should start with a “unified, widely-endorsed, national vision” that specifies goals related to industrial competitiveness, environmental compatibility, safety, and security. *System in Peril* also recommends a process by which air transportation system planning is driven by the needs of system users and the nation as a whole. Central to this process is the interagency development of operational concepts based on desired capabilities for the air transportation system. *President’s Commission Report*, on the other hand, takes a broader view and recommends a government-wide management structure and an integrated federal planning and budgeting process for developing national aerospace policy and an aerospace sector budget that coordinates spending across the government. *For Greener Skies* is less detailed in its recommendations, calling for a national strategy for coordinating agency budgets and allocating funds based on long-term, national goals.

Both *Future Flight* and *System in Peril* emphasize a lack of needs, and feasibility, analysis to guide development of aeronautics research, but each report looks at the problem a bit differently. *Future Flight* explains why the Small Aircraft Transportation System (SATS) “presents a highly unlikely and potentially undesirable outcome.” Although the report authors endorse most of the technological R&D contained in the SATS program, the report also shows how the SATS concept does not address the root causes of aviation congestion. As a result, the report recommends undertaking a series of studies on civil aviation needs to help prioritize research. *System in Peril* takes a broader look at the air transportation system and recommends developing research requirements based on how a future air transportation system will fit in the wider international transportation system.

Nearly all of the reports make recommendations that address inadequate government-wide coordination of aeronautics research activities and a lack of collaboration with other stakeholders. *Future Flight* recommends that NASA work with the Department of Transportation (DOT) and the FAA to define needs and opportunities for research. *President’s Commission Report* recommends establishing a Joint Program Office for transforming the air transportation system, and both *Persistent and Critical Issues* and *5-Year R&D Plan* support the recent creation of such an office. Most of the reports also call for strengthened partnerships with industry to enhance the safety of air travel and to accelerate the commercialization of new technologies.

Several reports call for additional aeronautics research funding and cite the decline in R&D funding over the years, both in real dollars and as a percentage of the NASA budget. *Commercial Supersonic Technology* recommends that the government fund technologies to a higher Technology Readiness Level (TRL) to fa-

cilitate transfer of technologies to industry, while *Persistent and Critical Issues, For Greener Skies*, and *President's Commission Report* recommend specific areas where federal dollars are needed to support research that is not being performed sufficiently by industry.

BARRIERS TO PROGRESS—PROBLEMS IN THE AVIATION INDUSTRY

The bleak national consequences of a diminishing aeronautics industry is exacerbated by the fact that continued advances are needed to keep up with the demand for air travel. According to *System in Peril*, the growth in demand for air travel is “the most critical long-term issue facing all aspects of the air transportation system.”¹⁰ *President's Commission Report* calls for specific goals related to this capacity barrier. Their report calls upon the nation to “demonstrate an automated and integrated air transportation capability that would triple capacity by 2025” and “reduce transit time between any two points on Earth by 50 percent.”¹¹ According to *System in Peril*, overcoming this barrier requires an innovative approach that will lay the foundation needed to “leap ahead” of current technology:

Most efforts to increase system capacity are focused on evolutionary or incremental changes that address specific constraints while aircraft are en route, in terminal areas, or on the ground at airports...Meeting demand over the next 25 to 50 years, however, is likely to require a more revolutionary approach that seeks to increase capacity significantly beyond the level that the system currently enjoys even under ideal weather conditions. This may require completely different system operating concepts.¹²

Commercial Supersonic Technology, *President's Commission Report*, and *For Greener Skies* all emphasize environmental barriers to growth of the aeronautics industry and make several recommendations to overcome those barriers. *For Greener Skies* also recognizes that environmental concerns are a major constraint on the ability of the air transportation system to accommodate future demand. The authors recommend funding research on advanced aircraft technologies that can help control noise and emissions at the source, rather than relying on short-term noise abatement at individual airports.¹³

Six reports call attention to the importance of improving the current accident rate to keep pace with growing demand for air travel. *Commission on Aviation Safety and Security* and *Avoiding Aviation Gridlock* focus on this problem, calling for a modernized airspace system, additional research to help prevent accidents, and more effective risk management programs.

¹⁰ *System in Peril*, p. 9.

¹¹ *President's Commission Report*, p. 9-8.

¹² *System in Peril*, p. 13.

¹³ *For Greener Skies*, p. 1.

Persistent and Critical Issues makes several recommendations to address the problem of a declining research, development, test, and evaluation (RDT&E) infrastructure. The report calls for increased ground and flight-testing capabilities and the funding necessary to support this infrastructure. This report, along with *President's Commission Report*, also calls attention to a decline in the aeronautics industry workforce. Neither report makes very specific recommendations to solve this problem, however. Recommendations include education reform and federally funded programs to attract and retain technical expertise.

Another common problem raised by the reports is the inadequate transition of government aeronautics technology to industry. Primary recommendations include advancing technologies to a higher TRL to reduce technical risk for industry and working more closely with industry to share needs and long-term research plans. *President's Commission Report* also recommends increasing the funding of airborne equipment normally purchased by airline manufacturers and airlines and streamlining certification processes.

RESEARCH AND TECHNOLOGY NEEDS— AIR TRANSPORTATION SYSTEM

System in Peril has the most extensive set of recommendations that call for additional research related to the national air transportation system. These research areas include the following:

- ◆ Distributed communication networks and decision-support tools
- ◆ Environmental impact of aviation (noise and emissions)
- ◆ Human factors and human-automation interaction
- ◆ Modeling and simulation and analytical and prediction tools
- ◆ Nontechnological factors.

Several reports examine in detail how NASA aeronautics research can best support air transportation system needs. At least five reports call for additional research in human factors and human-automation interaction, and in modeling and simulation and analytical and prediction tools.

RESEARCH AND TECHNOLOGY NEEDS— AIR VEHICLES

The reports recommend several research areas to address problems related to air vehicles:

- ◆ Aerodynamics
- ◆ Propulsion systems
- ◆ Alternative power sources
- ◆ Cockpit displays
- ◆ Composite materials
- ◆ Flight control systems and software
- ◆ Nanotechnology
- ◆ Systems engineering, and design and integration tools
- ◆ Aging of nonstructural components
- ◆ Applications to specific vehicles.

System in Peril, *Commercial Supersonic Technology*, and *Persistent and Critical Issues* offer the most recommendations pertaining to research in air vehicles. *System in Peril* focuses on aircraft technologies that can help support the air transportation system through increased efficiencies, less environmental damage, and compatibility with long-term operational concepts. *Commercial Supersonic Technology* focuses on technologies that offer the greatest potential to advance supersonic flight at speeds up to Mach 2. *Persistent and Critical Issues* focuses on critical enabling technologies for maintaining national aeronautic leadership.

ASSESSMENT

We assigned each of the 35 problem areas a severity score based on the number of times the problem appeared in the 11 reports and how strong the problem appeared to be in each report. Each time a problem was a higher-priority recommendation in a report, it received two points, while a problem that got less attention received one point. We added these points across all 11 of the reports, for each problem subcategory, and calculated the mean severity score and standard deviation. Problems with scores falling one standard deviation above the mean were categorized as high-priority problems, while those with scores falling one standard deviation below the mean were characterized as low-priority problems. Most of the problems fell within

one standard deviation from the mean and were categorized as medium-priority problems. This approach clearly assumes that each external report was of equal value and relevance. Table 2-2 presents the results.

Table 2-2. Severity of Problems

No.	Topic	Severity
Threats to our nation		
1	Reduced U.S. technological advantage and leadership	High
2	Declining U.S. market share and economic strength	High
3	Negative environmental effects	Medium
4	National security risks	Medium
Barriers to progress—problems in our government		
5	Lack of national leadership	Medium
6	Lack of clear objectives, strategy, and guidance	High
7	Inadequate processes for developing goals and budgeting for, managing, and evaluating R&T programs	High
8	Lack of well-formulated, realistic goals and timelines	Medium
9	Lack of needs- and feasibility-analysis to guide definition of R&T programs	Medium
10	Misdirected and inefficient use of resources	Medium
11	Inadequate government-wide coordination of aeronautics R&T	High
12	Lack of collaboration with other stakeholders	High
13	Weakening commitment to aeronautics R&T investment	High
Barriers to progress—problems in the aviation industry		
14	Limited capacity of current air transportation system and inadequate performance	High
15	Constraints resulting from negative impact of emissions	Medium
16	Constraints resulting from negative impact of noise	Medium
17	Safety hazards	Medium
18	Declining RDT&E infrastructure	Medium
19	Declining workforce	Low
20	Inadequate transition of government aeronautics technology to industry	Medium
Research and technology needs—air transportation system		
21	Distributed communication networks and decision-support tools	Low
22	Environmental impact of aviation	Low
23	Human factors and human-automation interaction	Medium
24	Modeling and simulation, analytical, and prediction tools	Medium
25	Nontechnological factors	Medium

Table 2-2. Severity of Problems

No.	Topic	Severity
Research and technology needs—air vehicles		
26	Aerodynamics	Medium
27	Propulsion systems	Medium
28	Alternative power sources	Medium
29	Cockpit displays	Medium
30	Composite materials	Medium
31	Flight control systems and software	Medium
32	Nanotechnology	Low
33	Systems engineering, and design and integration tools	Low
34	Aging of nonstructural components	Low
35	Applications to specific vehicles	Medium

SUMMARY

Specific findings and recommendations in the 11 reports can be summarized as follows:

- ◆ It is in the national interest to maintain global leadership in aerospace in an increasingly competitive environment, and to that end, the United States should invest in aeronautics research and development. The U.S. government should increase its investment in aeronautics infrastructure, workforce, and NASA-sponsored research. The United States also must engage in international issues related to aeronautics.
- ◆ The U.S. government needs to provide leadership and a vision to set national goals for aeronautics and air transportation. Aeronautics leadership and research require a coordinated effort involving NASA, other government agencies, industry, and academia.
- ◆ A transformational, forward-looking, centrally directed research and implementation effort is needed to meet the projected demand for air transportation in the future.
- ◆ NASA should develop partnerships and mechanisms to encourage and accelerate the transition of technology into products. The government should also lead the development of future operational concepts in partnership with other stakeholders.
- ◆ The principal focus for safety should be on reducing the rate of accidents by a factor of five; this effort will require a focused strategic plan, more effective safety risk management programs, and a global approach.

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- ◆ The federal government must lead the fight against security threats, commit greater resources to improving aviation security, and work cooperatively with the private sector and local authorities.
 - ◆ NASA should put a priority on airframe and propulsion technologies to improve performance, reduce fuel consumption, and foster innovative vehicle concepts. NASA should also enhance its capabilities for vehicle design, test, and flight evaluation.

Appendix A

Executive Summaries of Reviewed Reports

This appendix contains the title pages and executive summaries of the 11 reports LMI reviewed for this study. They appear in the following order:

- ◆ Commission on Aviation Safety and Security
- ◆ Avoiding Aviation Gridlock
- ◆ Recent Trends
- ◆ Commercial Supersonic Technology
- ◆ Future Flight (SATS)
- ◆ President's Commission Report
- ◆ Assessing Visions and Goals
- ◆ For Greener Skies
- ◆ Persistent and Critical Issues
- ◆ System in Peril
- ◆ 5-Year R&D Plan.

**White House Commission on
Aviation Safety and Security
FINAL REPORT
TO
PRESIDENT CLINTON**



**VICE PRESIDENT AL GORE, CHAIRMAN
FEBRUARY 12, 1997**

February 12, 1997

President William J. Clinton

The White House

Leadership in aviation goes far beyond having strong, competitive airlines. It means assuring leadership in communications, satellite, aerospace, and other technologies that increasingly are defining the global economy. It means more than the highest possible levels of safety and security for travelers.

The Commission's report reflects a focus on this vision: to ensure greater safety and security for passengers; to restructure the relationships between government and industry into partnerships for progress; and to maintain global leadership in the aviation industry.

Key Recommendations

In the area of safety, the Commission believes that the principal focus should be on reducing the rate of accidents by a factor of five within a decade, and recommends a re-engineering of the FAA's regulatory and certification programs to achieve that goal.

In the area of air traffic control, the Commission believes that the safety and efficiency improvements that will come with a modernized system should not be delayed, and recommends that the program be accelerated for to achieve full operational capability by the year 2005. In addition, a more effective system must be established to finance modernization of the National Airspace System and enhancements in safety and security.

In the area of security, the Commission believes that the threat against civil aviation is changing and growing, and that the federal government must lead the fight against it. The Commission recommends that the federal government commit greater resources to improving aviation security, and work more cooperatively with the private sector and local authorities in carrying out security responsibilities.

Although not specifically directed to do so, the Commission also took up the issue of responding to aviation disasters. In this area, the Commission believes that a better coordinated and more compassionate response is necessary, and that the responsibility for coordinating the response needs to be placed with a single entity. The Commission is pleased with the progress made to date in this area, including the designation of the National Transportation Safety Board as that single entity.

Many of the Commission's recommendations apply equally to each of the three major areas of focus, including those relating to regulation and certification. Primary among these recommendations is the call for greater use of partnerships in meeting goals. Regulatory and enforcement agencies such as the Customs Service, the Occupational Safety and Health Administration, and the Food and Drug Administration have put new emphasis on partnerships with industries, and are achieving tremendous results: seizing more drugs while expediting travel for legitimate travelers; reducing workplace accidents while increasing productivity; and getting important new AIDS and cancer-fighting drugs to market in a fraction of the time it used to take.

The premise behind these partnerships is that government can set goals, and then work with industry in the most effective way to achieve them. Partnership does not mean that government gives up its authorities or responsibilities. Not all industry members are willing to be partners. In those cases, government must use its full authority to enforce the law. But, through partnerships, government works with industry to find better ways to achieve its goals, seeking to replace confrontation with cooperation. Such partnerships hold tremendous promise for improving aviation safety and security. A shift away from prescriptive regulations will allow companies to take advantage of incentives and reach goals more quickly.

Transportation Secretary Peña's cooperative program with airlines to establish a single level of safety is an example of innovative government-industry partnership. Another is Vice President Gore's January 15, 1997 announcement that Boeing, in concert with government agencies, had developed a plan to modify the rudders on hundreds of its 737 aircraft. By acting without waiting for a government mandate, Boeing will complete many of these safety-enhancing modifications before the government could complete a rule requiring the action.

Partnership must extend not only to regulated entities, but also to the various federal agencies involved with aviation safety and security. A number of agencies outside the Department of Transportation have expertise and resources that can have a direct

impact on improving safety and security. The Commission urges the Administration to continue to work to expand and improve these intergovernmental relationships.

In the last few years, the FAA has begun to recognize and respond to the tremendous changes it faces. Reviews such as the Challenge 2000 report examined ways of improving the way the FAA regulates operators and manufacturers. Now is the time for the FAA to build on that work, and aggressively reengineer itself to adapt to the demands of the 21st Century.

It is important to note that the FAA, alone among federal agencies, has been given some critical new tools to help shape its own future. A new Management Advisory Council will provide valuable input to the agency's decision-making process. In 1995, the Congress granted the Clinton Administration's request for unprecedented reforms of the FAA's personnel and procurement systems. These reforms give the FAA almost unlimited latitude to design new systems to meet the agency's unique and particular needs. The first phases of these reforms were implemented in April 1996, and are already producing dividends. The FAA used to have 233 procurement documents, and today there are less than 50. Using its streamlined process, the FAA recently completed a billion dollar procurement in six months, with no protests. Under the old system, it would have taken three times as long, and likely would have been delayed by costly protests. A stack of personnel rules that used to be one-foot high has been reduced to 41 pages, and will allow the agency to hire people where they're needed and when they're needed.

This flexibility will be critical to meeting the challenges of the next century. As former FAA Administrator David Hinson recently noted, this type of reform is "the seed for what needs to happen at the FAA." The incoming leadership at the Department of Transportation and the FAA must utilize fully the flexibilities that have been granted if the agency is to keep pace with the rapidly changing industry it regulates.

Responsibility for Implementing Change

The Commission's goal for aviation in the next century may be summed up by the words of Robert Crandall, Chairman of American Airlines, when he said, "We would like the public to take safety and security as a given. If that is going to happen, change is necessary."

The responsibility for achieving that change lies with all the partners in aviation. The Administration, the Congress, the entire aviation industry and its employees must work together to make the changes that are necessary to keep pace with the challenges facing them. Commitments must be made at the highest levels of every organization, in government and in the private sector.

To ensure that the government remains focused on the goals established in this report, the Commission recommends three steps:

- (1) that the Secretary of Transportation report publicly each year on the implementation status of these recommendations;
- (2) that the President assign the incoming leadership at the Department of Transportation and the FAA the clear mission of leading their agencies through the necessary transition to re-engineered safety and security programs; and
- (3) that the performance agreements for these positions, which the documents that senior managers sign with the President outlining their goals and specific means of measuring progress, include implementation of these recommendations.

Chapter One:

Improving Aviation Safety

NCARC Report Avoiding Aviation Gridlock & Reducing The Accident Rate

Norman Y. Mineta, Chair

AVOIDING AVIATION GRIDLOCK

&

REDUCING THE ACCIDENT RATE

A Consensus for Change

December 1997

December 11, 1997

Honorable Rodney E. Slater

Honorable Jane F. Garvey

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PART 1

EXECUTIVE SUMMARY

The National Civil Aviation Review Commission was charged with developing two distinct reports -- one on funding the nation's civil aviation programs and another on aviation safety. While the reports are distinct, the Commission believes that the issues of better funding mechanisms and improved safety performance are inextricably linked.

COMMISSION FINDINGS AND RECOMMENDATIONS ON FUNDING

The aviation system of the United States is at a critical crossroads. Aviation activity is growing, the technology of aviation is changing rapidly, and the business of aviation is becoming more complex.

Yet, a critical piece of aviation's future is in doubt. The Federal Aviation Administration (FAA) currently lacks the organizational, management, and financial wherewithal to keep pace with the dynamic aviation community. Unless the FAA and various aviation stakeholders -- the Congress, the Executive Branch, and the aviation community -- change the status quo, internal and external to the FAA, our nation's aviation system will succumb to gridlock. Delays will skyrocket while we reminisce about the "reliable" flight schedules of the past. This current course will impair our domestic economy, reduce our standing in the global marketplace, and result in a long term deterioration of aviation safety. In this regard, the Commission has made several critical findings.

Findings on Funding

- Gridlock is near and will be expensive. Traffic data and trends indicate that adding just a few minutes of delay to each airline flight in the United States will bring the aviation system to gridlock with dramatic negative impacts on the economy. The airline industry's complicated schedules are based on precise and efficient air traffic control technology and management. Rapidly growing demand combined with a reduction in capacity, as the result of continued reliance on outdated equipment, will bring our nation's aviation system to gridlock soon after the turn of the century. Gridlock could also have safety implications as pressures to meet flight schedules grow just at a time when capacity is increasingly being constrained.
- Federal budget rules are crippling. The present system of federal budget regulation is inappropriate

for a system controlling commercial operations that needs to be driven by demand for services. Budget rules that govern the federal aviation system must be revised. The money problem that faces the FAA is an inability to access the revenues collected for its use.

- There are "too many cooks", making authority and accountability too diffused. Authority and accountability are too diffused to run a 24 hour-a-day, high technology, rapidly changing operating system for a major commercial industry. Everyone responsible for the current air traffic control (ATC) system -- the FAA, the DOT, the aviation industry, the Administration, and the Congress -- wants to make the system work. But there are too many people in charge. The problems are systemic and require basic changes in command and control.
- FAA is nearsighted. While the vast majority of individual FAA employees remain dedicated and professional, the FAA as an institution impedes needed modernization by not focusing enough on determining and meeting its external users' needs for high quality and modern services at reasonable costs. Modern business tools, such as a cost accounting system, that tie specific costs to services, and measurement tools that assess how well services are provided are not yet available. Incentives are needed for the FAA's culture to become more externally focused on users and services, more businesslike, and more responsive.
- Increasing operational costs overshadow capital investments. The funding system forces trade-offs, which substitute operational costs for capital investments. The system is in a downward spiral where increasing operation and maintenance costs, driven by outdated equipment, are "freezing out" new investments under current federal budget cap assumptions. Future system capacity will be reduced in real terms from today's capacity.
- Airport needs are not being met. Airport-related congestion will increase in the future without a strong federal commitment of resources. Airport capital investments must go hand-in-hand with ATC investment to maintain system capacity.
- International competitive stature will be hurt. Historically, the U.S. has been the leader in air traffic management and technology. However, other countries are now or soon will be moving ahead of the United States in making improvements to their aviation infrastructure. Falling behind other countries in making critical capital investments will certainly affect the international competitive position of the U.S.

The National Civil Aviation Review Commission believes these problems can be rectified, but it will take dramatic changes in the way that the air traffic system and airport development are managed and financed. Institutional relations within the FAA and among the various stakeholders must be altered if we are to increase accountability at the agency, improve management performance, and ensure that resources are sufficient and used effectively.

These problems have been identified by previous Commissions and analyses. Among these are the National Commission for a Strong Competitive Airline Industry (1993), the Clinton Administration Air Traffic Control Corporation Study (1994), the White House Commission on Safety and Security (early 1997), and the Coopers & Lybrand FAA-Independent Financial Assessment (early 1997). While these problems are not new, there is now a realization and a consensus as to their seriousness and implications.

Recommendations on an Integrated and Comprehensive Funding

Package

Meeting the demands of a growing, complex aviation system is no small task. In the funding report, the Commission recommends broad and sweeping changes in the ways the FAA is managed, sets its priorities, assesses and achieves performance outcomes, and is financed. As a package, these reforms put the FAA and aviation stakeholders in position to take advantage of industry growth and technological change.

The Commission has agreed on a set of five broad recommendations that stem from their findings. The recommendations are viewed as a comprehensive package and are strongly supported by all Commissioners. Any alternative to the Commission's proposal must demonstrate similar consensus to be credible. It must be recognized that the strong agreement within the Commission for these recommendations exists because they are viewed as a comprehensive package. Moving forward on implementing some elements of the package without the others being addressed would result in a loss of unanimity. The importance of this consensus is demonstrated by the shortfall of previous efforts, which lacked full public and industry support to reform the FAA. The Commission's recommendations are included, as appropriate, in the proposed legislation in Attachment 1, and are summarized below.

- FAA's budget treatment must change. The Commission recommends that the FAA's funding and financing system receive a federal budget treatment ensuring that revenues from aviation users and spending on aviation services are directly linked and shielded from discretionary budget caps. This will ensure that FAA expenditures will be driven by aviation demand.
- FAA's management must become performance based. The Commission recommends that services related to the air traffic system be placed in a Performance Based Organization (PBO), which is managed by a Chief Operating Officer and overseen by a board of public interest directors. In addition, the FAA should institute a cost accounting system and be given authority to implement innovative programs involving leasing and borrowing authority. The Commission further recommends that the safety and security functions of the FAA, which are separate from the PBO, should also adopt a performance based management philosophy so that the quality of these programs can be improved.
- FAA's revenue stream must become more cost based. The Commission recommends that the FAA adopt a cost-based revenue stream to support its air traffic system activities including capital investments. At the same time, funding for aviation security, safety, and government use of the air traffic system should be provided by the federal government's general fund.
- FAA must control its operating costs and increase capital investments. The Commission has reviewed the FAA's forecasted budget needs and assumes the agency's budget projections to be reasonable in a status quo environment. However, the Commission recommends that FAA operating costs could be better managed and controlled and that investments in air traffic control modernization should be increased.
- Airport capital needs must be met. The federal requirements of airport capital development currently exceed the amount of revenue presently available to finance these requirements. The Airport Improvement Program (AIP) is the linchpin of airport financial planning and the Commission believes AIP should be funded at a minimum of \$2 billion annually over the next five

years.

These funding-related recommendations are strongly interconnected. Without budget treatment that links aviation revenues and spending together, key capital investments will not be made despite industry's willingness to pay. Without movement to a cost-based system, FAA's improved performance will be limited because the agency will lack critical data to judge performance and appropriate market signals to make sound investment decisions. Without management and organizational changes, there will be no guarantee that any dollar that goes into the FAA is used wisely and efficiently.

These connections are the basis for why the Commission's recommendations are comprehensive and sweeping. It is the belief of the Commission that without these changes, the aviation system infrastructure of this country will become an impediment to economic growth. Critics of these proposals, or defenders of the status quo, must provide a compelling alternative, because the current system is headed down a path toward economic disaster and reduced safety. Since this is unacceptable, the Commission offers its funding report as a clarion call to action and innovation.

COMMISSION FINDINGS AND RECOMMENDATIONS ON AVIATION SAFETY

The Commission was charged to look at the ability of the Federal Aviation Administration (FAA) to anticipate changes in the aviation industry and develop policies and actions to ensure the highest level of aviation safety in the 21st century. The Commission was also directed to examine some specific safety issues.

Commercial aviation is an extraordinarily safe human endeavor. The risk of perishing in a commercial aircraft accident is about one in every two million flights. This safety record is due to the high standards that exist in the building and operation of commercial aircraft. These high standards are the result of decades of strong interaction between government regulators and safety professionals within the aviation industry.

Even with this excellent safety record, there is a growing sense that the high level of public confidence in the safety of the aviation system will slowly erode over the next 10-15 years if significant steps are not taken to further improve aviation safety.

Findings on Aviation Safety

- The commercial aviation accident rate is extraordinarily low, but it has shown virtually no improvement over the past 30 years. By the end of the 1960s, the large-transport aircraft fleet had become mostly jet powered. The introduction of highly reliable jets into commercial aviation resulted in a dramatic, multifold reduction in the accident rate, but since that time the accident rate has remained virtually unchanged.

- A flat accident rate coupled with the anticipated healthy growth in aviation will lead to a significant increase in the absolute number of accidents. If there is no change in the accident rate, and the anticipated growth occurs, there will be a large airliner accident somewhere in the world every 7-10 days by the year 2010.
- The public, their government representatives, and the aviation industry will find an increasing number of accidents wholly unacceptable. Public interest in aviation safety runs very high, with demands for improvements ever present. If the public perceives that air transportation safety is deteriorating, the demands for improvement will become increasingly strong.
- The accident rate must be reduced significantly. Safety professionals in industry and government believe that the current rate should and can realistically be reduced by 80%.

Recommendations on Aviation Safety

The Commission believes that the accident rate can be reduced, but this will take a comprehensive and concerted program by government and industry that will require new ways of doing business with each other and a greater emphasis on cooperation and collaboration.

- FAA and the aviation industry must develop a strategic plan to improve safety, with specific priorities based on objective, quantitative analysis of safety information and data. Presently, there is no agreed upon safety improvement strategy; rather there are many tactical efforts at work. Without a comprehensive strategy, priorities are allowed to fluctuate and progress toward safety improvement is slowed.
- Aviation safety programs in industry and government need to be improved by establishing more effective safety risk management programs. This should include self-audit and self-disclosure programs within aviation companies, protecting and sharing safety information in non-punitive ways, and encouraging research to support these activities. Where possible, these programs should include the analysis of real flight and operational data. The aviation community must look deeper than accidents and incidents to identify latent and emerging problems and fix them before a mishap occurs. There needs to be a willingness in government and industry to invest in new ways of doing business. This will require changes in the traditional regulatory relationship so that tools beyond the simple enforcement of rules are available to improve safety.
- FAA safety programs need to become performance-oriented. The FAA must establish performance measures to focus resources and hold the agency's safety management accountable to make improvements.
- Government and industry should expand on their programs to improve aviation safety in other parts of the world. There are areas of the world where the accident rate is significantly higher than it is in the U.S. It is in the U.S. traveling public's interest, as well U.S. commercial and trade interests, to see that safety is improved everywhere, not just in the U.S.

The safety report also provides analysis and recommendations on a number of specific issues: the use of suspected unapproved aircraft parts, electronic maintenance record keeping, staffing and training of FAA safety personnel, runway incursions, flight data recorders, and FAA oversight in the future.

Recent Trends in U.S. Aeronautics Research and Technology

Committee on Strategic Assessment of U.S. Aeronautics
Aeronautics and Space Engineering Board
Commission on Engineering and Technical Systems
National Research Council

number of new commercial and military development programs for military and commercial aircraft has been significantly reduced. In this environment, developing experimental aircraft is one approach for maintaining the skills of aircraft designers. Furthermore, in the experience of committee members, the cutting edge of aeronautics R&T is most attractive to young, talented engineers and scientists. Therefore, continued reductions in aeronautics R&T would damage the personnel base required to maintain a robust, competitive aeronautics industry capable of supporting U.S. national security and economic interests.

Although knowledgeable observers may differ in their assessments of the degree of the severity of the consequences, the committee wishes to point out that continued reductions in funding for aeronautics R&T may have irreversible consequences. Once the position of the United States in aeronautics is lost, it will be exceedingly difficult to regain because of the difficulty in reassembling the infrastructure, people, and investment capital.

RECOMMENDATIONS

This committee agrees with the findings of many previous studies:¹¹

- Aeronautics as an ongoing enterprise is important to national security, the national economy, and the quality of life in the United States.
- Aeronautics R&T is important to the aeronautics enterprise in the United States.

The committee concluded that consolidations in the aeronautical industry, especially in the airframe development and manufacturing industry, the end of the Cold War, and the increasing globalization of the aircraft industry do not affect the general requirements for facilities and other resources essential to effective aeronautics R&T. In some instances recommendations from the earlier studies have taken on greater urgency. The continuing decline in the U.S. market share for commercial jet transport aircraft, recent regional conflicts, and the Air Force's decision to devote more of its assets to space developments and operations in an era of declining overall budgets have made the needs for strong support for aeronautics R&T more urgent.

The committee agrees with the conclusion reached by other studies that government funding of aeronautics R&T is worthwhile.¹² In particular, the committee endorses the three key goals identified by the National Science and Technology Council:¹³

- Maintain the superiority of U.S. aircraft and engines.
- Improve the safety, efficiency, and cost effectiveness of the global air transportation system.
- Ensure the long-term environmental compatibility of the aviation system

¹¹ For example, National Science and Technology Council (NSTC). 1995. Goals for a National Partnership in Aeronautics Research and Technology. Washington, D.C.: Office of Science and Technology Policy. Available on-line at "www.whitehouse.gov/WH/EOP/OSTP/html/aero/cv-ind.html".

¹² Ishaq Nadiri. 1993. Innovations and Technological Spillovers. NBER Working Paper Series. Working Paper No. 4423. August, 1993. Also, Edwin Mansfield, J. Rapoport, A. Romeo, S. Wagner, and G. Beardsley. Social and Private Rates of Return from Industrial Innovations. Quarterly Journal of Economics. Vol 77, pp 221–240. 1977.

¹³ NSTC, *op cit*.

The committee endorses NASA's response to these challenges, in which it defined three pillars, supported by 10 technology enabling goals (see Box 1). The second and third goals of the National Science and Technology Council can be considered as broadening the old "higher, farther, faster" pure performance objectives of the past. Where the National Advisory Council for Aeronautics (NACA, the predecessor to NASA) and the military were once the primary federal organizations involved in aeronautics R&T, now the Department of Defense, NASA, the U.S. Department of Transportation (including the Federal Aviation Administration), and the National Science Foundation all have significant R&T programs related to aviation. The focus of each program is determined by each agency's missions, legislative charter, and annual budget appropriation. The importance of coordination among these agencies is increasingly important for at least three reasons:

- The result of the overlapping responsibilities arising naturally from greater density of aviation operations and the growing sophistication of flight systems, which are increasingly dependent on electronics, optics, and computers.
- The burgeoning costs to develop increasingly capable aeronautical systems under the pressure of constrained budgets.
- The widespread acceptance in the military of "dual-use science and technology" (combining civil and military applications) and commercial-off-the-shelf equipment and systems for military applications. As stated by the National Science and Technology Council, "Nationally we have the infrastructure—government, industry and universities—to maintain leadership. We must now renew our focus on partnership to meet national challenges and accomplish national goals."¹⁴

The committee recommends that major improvements be made in the coordination of aeronautics R&T activities among NASA, the Department of Defense, the Federal Aviation Administration, industry, and academia. An overarching organization for national aeronautics R&T is needed to speak for national values, ensure efficient use of resources, make cooperative actions more productive, and eliminate duplication where it is not an effective motivator of competition. Successful collaborative programs (e.g., AGATE, NRTC, and IHPTET¹⁵) should be examined to identify characteristics adaptable to this purpose.¹⁶

Aeronautics is an R&T-intensive enterprise. The committee is convinced that continued reductions in government support of aeronautics R&T would jeopardize (1) the ability of the United States to produce preeminent military aircraft and (2) the ability of the aeronautics sector of the U.S. economy to remain globally competitive. A rigorous proof of this conclusion requires detailed military, technical, and economic analyses that the committee was unable to complete during this brief study. However, the committee is greatly concerned that ongoing reductions in R&T, which seem to be motivated primarily by the desire to reduce expenditures in the near term, are taking place without an adequate understanding of the long-term consequences. The committee recommends that the federal government analyze the national security and economic implications of reduced aeronautics R&T funding before the nation discovers that reductions in R&T have inadvertently done severe, long-term damage to its aeronautics interests.

¹⁴ Ibid.

¹⁵ That is, the Advanced General Aviation Transport Experiment, National Rotorcraft Technology Center, and Integrated High Performance Turbine Engine Technology.

¹⁶ At issue are such considerations as the balance among long-term and short-term research, how and when to require industry and/or university cost sharing, peer reviews for proposals, protection of rights to "intellectual property" (proprietary rights), and the extent of budgetary authority and availability.

In addition, for the United States to succeed in the globalized world aviation market, the nation requires clearly defined national objectives for aeronautics R&T. These objectives should be established considering our national requirements and how they can best be satisfied with active participation from industry and government developers as well as the military and commercial technology users of aeronautics R&T results. Continuing inputs from these four components are crucial to the implementation of technologies needed to keep the United States militarily secure and globally competitive.

BOX 1 **NASA's Aeronautics Goals**

In March 1997, NASA's Office of Aeronautics and Space Transportation Technology adopted 10 enabling technology goals to guide pre-competitive research in long-term, high-risk, high-payoff technologies. The goals are in three groups or "pillars":

- ◆ **Global Civil Aviation**
 - reducing the aircraft accident rate
 - reducing emissions
 - reducing perceived noise levels
 - increasing aviation system throughput
 - reducing the cost of air travel
- ◆ **Revolutionary Technology Leaps**
 - reducing travel time to the Far East and Europe
 - invigorating the general aviation industry
 - developing advanced design tools and experimental aircraft
- ◆ **Access to Space**
 - reducing the cost of launching payloads to low-Earth orbit by an order of magnitude by 2007
 - reducing the cost of launching payloads to low-Earth orbit by another order of magnitude by 2020

Source: *Aeronautics and Space Transportation Technology: Three Pillars for Success*, NASA Office of Aeronautics and Space Transportation Technology, Washington, D.C., March 1997.

Commercial **SUPERSONIC** Technology

The Way Ahead

Committee on Breakthrough Technology for Commercial Supersonic Aircraft
Aeronautics and Space Engineering Board
Division on Engineering and Physical Sciences
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C.

Executive Summary

High-speed flight is a major technological challenge for both commercial and business aviation. As a first step in revitalizing efforts by the National Aeronautics and Space Administration (NASA) to achieve the technology objective of high-speed air travel, NASA requested the National Research Council (NRC) to conduct a study that would identify approaches for achieving breakthroughs in research and technology for commercial supersonic aircraft. This report documents the results of that effort. It describes technical areas where ongoing work should be continued and new focused research initiated to enable operational deployment of an environmentally acceptable, economically viable commercial aircraft capable of sustained supersonic flight, including flight over land, at speeds up to approximately Mach 2 in the next 25 years or less. In particular, sonic boom is the major barrier to development of supersonic business jets (SBJs) and a major, but not the only, barrier to the development of supersonic transports with overland capability. While NASA should have its eye on the grand prize—supersonic commercial transports—it is still quite appropriate for NASA to conduct sonic boom research, even when related to SBJs. The report also identifies other critical areas where technology development is needed to support the development of commercial supersonic aircraft with cruise speeds beyond Mach 2.

STUDY OBJECTIVE AND APPROACH

The objective of this study was to leverage the results of NASA's High Speed Research (HSR) Program, other research, and related studies to identify breakthrough technologies for overcoming key barriers to the development of an environmentally acceptable, economically viable commercial supersonic aircraft with minimal sonic boom (to enable supersonic flight over land). The scope of the study included both small aircraft (that is, SBJs) and large transports. The focus of the study was on high-risk, high-payoff technolo-

gies where NASA-supported research could make a difference over the next 25 years. The committee did not focus on any specific vehicle configuration, market segment, or technology readiness level (TRL), although it believes that, to have practical value, government-funded research should advance to a TRL of at least 6 before industry can be expected to incorporate new technologies into commercial aviation products.¹

The committee considered which of two options it would focus on:

1. revolutionary new types of aircraft that are fundamentally different from existing aircraft
2. vehicles that more closely resemble existing aircraft

Both options require breakthrough technologies, but developing a new vehicle concept into an operational commercial supersonic aircraft would take decades of research and development to satisfy aircraft performance, economic, safety, certification, and environmental requirements. Focusing on revolutionary vehicle concepts to develop commercial supersonic aircraft would probably give NASA a research program that does little or nothing to enable operational deployment of commercial supersonic aircraft within the next 25 years. Because that is the time frame of interest for this study, the committee concentrated on identifying areas where breakthroughs and focused investments are most likely to achieve the ultimate objective of sustained commercial supersonic flight, including flight over land, in a more timely fashion.

As the study proceeded it became clear that the statement of task presented procedural challenges. Breakthrough tech-

¹NASA rates the level of technology readiness on a scale of 1 to 9. TRL 6 has been achieved when a system or subsystem model or prototype has been demonstrated in a relevant environment.

nologies are likely to be guarded as proprietary and competition-sensitive and are not available to groups such as NRC committees, which work in a public forum. This was true for much of the results of the HSR Program, which is not yet public information, as well as details of ongoing work, such as the Quiet Supersonic Platform Program funded by the Defense Advanced Research Projects Agency (DARPA). Because of its limited access to detailed technical data, the committee was reluctant to accept the role of recommending which individual technical concepts and approaches, many of them in the early stages of development, should be funded. Fortunately, it was not necessary for the committee to do so. As demonstrated by the Quiet Supersonic Platform Program, once the government identifies specific areas of interest and allocates development funding, industry and other research organizations are able and willing to provide detailed, innovative research proposals within the framework of a competitive government acquisition program, where competition-sensitive information is more likely to be protected. Therefore, with the concurrence of the study sponsor, the committee carried out the intent of the statement of task using the following approach:

1. Identify the technical barriers to sustained commercial supersonic flight, including flight over land.
2. Characterize the gap between the state of the art and the technology required to overcome each barrier.
3. Establish the feasibility of closing each gap by considering if at least one promising approach is available.
4. Identify what would have to be demonstrated to show that the gap has been closed.

TECHNOLOGY CHALLENGES

To provide a framework for analyzing the technology needs for commercial supersonic flight over the next 25 years, the committee defined a set of three notional supersonic vehicles:

- *Small.* An SBJ with about 8 to 15 passengers, a range of 4,000 to 5,000 nautical miles (NM), a cruise speed of about Mach 1.6 to 1.8, and sonic boom low enough to enable supersonic flights over both land and water.
- *Medium.* An overland supersonic commercial transport with about 100 to 200 passengers, a range of 4,000 to 5,000 NM, a cruise speed of about Mach 1.8 to 2.2, and sonic boom low enough to enable operations over both land and water.
- *Large.* A high-speed civil transport (HSCT) with about 300 passengers, a range of 5,000 to 6,000 NM, and a cruise speed of about Mach 2.0 to 2.4.

The committee also compared the technical challenges for commercial supersonic aircraft with the likely challenges for a military supersonic strike aircraft. A strike aircraft would have to overcome many of the same challenges as a

commercial aircraft—for example, a high lift-to-drag ratio and acceptable takeoff and landing characteristics; efficient and durable engines; and advanced airframe materials and structures. A strike aircraft would need to meet these challenges while also meeting military requirements for stealth and weapons integration, but without necessarily meeting all the same environmental constraints.

For each class of aircraft, the committee used a combination of engineering judgment, historical trends, and simplified equations to identify key challenges and the research areas required to overcome those challenges. While noise and emissions are certainly major barriers to the development of an HSCT, significant advances in the traditional aeronautics engineering disciplines, such as structures, propulsion, and aerodynamics, are still required to close the business case and certificate new systems. Supersonic transports with overland capability (and military strike aircraft of comparable size) will require improvements in the four major factors related to economics (lift-to-drag ratio, air vehicle empty weight fraction, specific fuel consumption, and thrust-to-weight ratio) equivalent to about 10 percent over the present state of the art in each parameter, as well as additional advances related to the environment and certification. For SBJs, most parameters are already within the state of the art. HSCTs, on the other hand, will require significant advances, equivalent to about 15 percent for each of the four major economic parameters. Affordable supersonic flight is an exercise in integration: A viable commercial supersonic aircraft cannot be achieved until solutions to the individual technology challenges are brought together in one integrated airframe-engine design.

The committee also validated the importance of cruise speed as a key factor in determining the technological difficulty associated with development of a commercial supersonic aircraft. NASA's HSR Program, which ran from 1985 to 1999, envisioned an HSCT with 300 passengers and a cruise speed of Mach 2.4. In 1997 the NRC concluded that the focus on Mach 2.4 was too aggressive and probably not justified by the business analysis. The study concluded that an aircraft with a cruise speed of Mach 2.0 might have a net productivity similar to that of a Mach 2.4 aircraft and would have an easier time overcoming some of the most difficult economic, technological, and environmental challenges.

As cruise speed increases, the most efficient cruise altitude increases also, and the technical challenges to developing an economically viable and environmentally acceptable commercial supersonic aircraft increase significantly above approximately Mach 2. For aircraft with cruise speeds less than Mach 2, an NO_x emission index of 15 appears satisfactory, and water vapor emissions are unlikely to pose difficulties at the associated altitudes. Aircraft with cruise speeds in excess of Mach 2 will normally cruise in the stratosphere, where engine emissions have a greater potential to cause climate change and depletion of atmospheric ozone. At higher speeds, the NO_x emissions index may need to be as low as 5.

In addition, water vapor, which is benign in the lower atmosphere, may have significant, long-lasting effects in the stratosphere. Also, at higher speeds air friction creates higher temperatures. For cruise speeds above approximately Mach 2.2, new structural materials are needed to meet requirements for strength, weight, and affordability. The noise suppression problem also becomes more challenging as speed increases, because cruise efficiency requirements mandate the use of engines with lower bypass ratios and, accordingly, higher jet exhaust velocities and more noise. As a result, larger nozzles are required to meet community noise standards. Without advanced technology, the nozzles of aircraft with cruise speeds above Mach 2.2 will probably be too large and heavy to be economical.

The intensity of sonic booms increases with vehicle size, weight, and speed; developing a low-boom design suitable for supersonic cruise over land will be much harder for an HSCT than for smaller transports or an SBJ. Even so, the development of any economically viable commercial supersonic aircraft is far from trivial. High-risk investments are still required to develop and validate the design of a small supersonic aircraft with low sonic booms. Success in this endeavor, however, could support the eventual development of an HSCT with a low sonic boom by performing critical

noise suppression experiments, testing public acceptance of sonic boom noise levels, and gathering critical data.

RECOMMENDATIONS FOR RESEARCH

The technology advances necessary to attain the economic and environmental goals will be easiest to achieve for an SBJ and most difficult for an HSCT. Surmounting the special technology challenges associated with cruise speeds greater than approximately Mach 2 will require long-term research. To achieve commercial supersonic flight by 2025, NASA's primary focus should be to support (1) new initiatives and (2) ongoing research that would enable supersonic flight at cruise speeds less than approximately Mach 2, where the technology challenges are more tractable in the near- to mid-term. Specific areas of research identified by the committee appear in the findings and recommendations below and are also shown in Table ES-1.

Finding 1. An economically viable, environmentally acceptable supersonic commercial aircraft with a cruise speed of less than approximately Mach 2 requires continued development of technology on a broad front (see Finding 2). In addition, research in the following five areas of critical impor-

TABLE ES-1 Key Challenges to Developing a Commercial Supersonic Aircraft and Related Research Areas

Characteristics of Supersonic Aircraft: Key Challenges											
Economics—range, payload, fuel burn, etc.											
Low weight and low empty weight fraction	2					2					
Improved aerodynamic performance		1	1		2						
Highly integrated airframe/propulsion system						1					
Low thrust-specific fuel consumption											
Long life	2	3								2	
Environment											
Benign effect on climate and atmospheric ozone											3
Low noise during takeoff and landing ^a		2	2	2					2	1	3
Low sonic boom		1				1		1			
Certification for commercial operations						2					
Acceptable handling and ride qualities				1		1	1				
Passenger and crew safety at high altitudes						2	2				

Airframe
Integrated Aircraft
Propulsion System

Related Research Areas

Long-Life, Lightweight Airframe Materials and Structures

Long-Life, High-Temperature Airframe Materials

Airframe Configurations

Laminar Flow

Flight-Critical, Highly Augmented Automatic Control Systems

Operational Procedures and Limitations for Noise Abatement

Synthetic Vision

Asio-propulsive aero-elastic and Aircraft Pilot Aero-elastic (APSE)

Design Tools and Methods

Certification Standards for New Technologies and Procedures

Cabin Depressurization Safety

Radiation Exposure Safety

Human Response to Sonic Booms

Propulsion Systems

Variable Cycle Engine

Lightweight Noise Suppression Systems

Long-Life, High-Temperature Engine Materials

Effects of Emissions (H₂O, NO_x, etc.) in the Stratosphere

NOTE: 1, research area recommended by Finding 1; 2, research area recommended by Finding 2; 3, research area recommended by Finding 3.

tance could lead to important breakthroughs, but only if current research is augmented by new, focused efforts (or significant expansions of existing efforts):

- airframe configurations to reduce sonic boom intensity, especially with regard to the formation of shaped waves and the human response to shaped waves (to allow developing an acceptable regulatory standard)
- improved aerodynamic performance, which can be achieved through laminar flow and advanced airframe configurations (both conventional and unconventional)
- techniques for predicting and controlling aero-propulsive servo-elastic and aircraft-pilot servo-elastic (APSE) characteristics, including high-authority flight- and structural-mode control systems for limiting both types of APSE effects in flight and tools for defining acceptable handling and ride qualities
- automated, high-fidelity, multidisciplinary optimization tools and methods for design, integration, analysis, and testing of a highly integrated, actively controlled airframe-propulsion system
- variable cycle engines for low thrust-specific fuel consumption, high thrust-to-weight ratio, and low noise

Recommendation 1. NASA should focus new initiatives in supersonic technology development in the areas identified in Finding 1 as they apply to aircraft with cruise speeds of less than approximately Mach 2. Such initiatives should be coordinated with similar efforts supported by other federal agencies (e.g., the DARPA Quiet Supersonic Platform Program).

In addition to focused research initiatives on the technologies listed in Finding 1, the development of economically viable, environmentally acceptable commercial supersonic aircraft also requires continued advances in other areas. A broad range of technical activity must be supported to ensure that other key technologies are mature enough to convince industry to take on development and to meet designer's needs at the time a supersonic transport is laid down. Although advances in these additional technologies (see Finding 2) may not be necessary to develop an SBJ, they are critical to the ultimate goal of developing a large commercial supersonic transport.

Finding 2. An economically viable, environmentally acceptable commercial supersonic transport with a cruise speed of less than approximately Mach 2 requires continued advances in many areas, particularly the following:

- airframe materials and structures for lower empty weight fractions and long life, including accelerated methods for collecting long-term aging data and the effects of scaling on the validity of thermomechanical tests

- engine materials for long life at high temperatures, including combustor liner materials and coatings, turbine airfoil alloys and coatings, high-temperature alloys for compressor and turbine disks, and turbine and compressor seals
- aerodynamic and propulsion systems with low noise during takeoff and landing
- cockpit displays that incorporate enhanced vision systems
- flight control systems and operational procedures for noise abatement during takeoff and landing
- certification standards that encompass all new technologies and operational procedures to be used with commercial supersonic aircraft
- approaches for mitigating safety hazards associated with cabin depressurization at altitudes above about 40,000 ft
- approaches for mitigating safety hazards that may be associated with long-term exposure to radiation at altitudes above about 45,000 ft (updating the Federal Aviation Administration's advisory circular on radiation exposure, AC 120-52, to address supersonic aircraft would be a worthwhile first step)

Recommendation 2. For the technologies listed in Finding 2, NASA should allocate most of the available resources on goals and objectives relevant to aircraft with cruise speeds of less than approximately Mach 2. NASA should focus remaining resources on the areas listed in Finding 3 (i.e., the highest risk areas for cruise speeds greater than approximately Mach 2). Again, NASA activities should be coordinated with similar efforts supported by other federal agencies.

Conclusion 1. Research and technology development in the areas listed in Findings 1 and 2 could probably enable operational deployment of environmentally acceptable, economically viable commercial supersonic aircraft in 25 years or less—perhaps a lot less, with an aggressive technology development program for aircraft with cruise speeds less than approximately Mach 2.

Finding 3. An economically viable supersonic commercial aircraft with a cruise speed in excess of approximately Mach 2 would require research and technology development in all of the areas cited in Findings 1 and 2. In addition, significant technology development would be needed to overcome the following barriers:

- climate effects and depletion of atmospheric ozone caused by emissions of water vapor and other combustion by-products in the stratosphere
- high temperatures experienced for extended periods of time by airframe materials, including resins, adhesives, coatings, and fuel tank sealants

- noise suppression at acceptable propulsion system weight

Conclusion 2. Candidate technologies for overcoming environmental barriers to a commercial supersonic aircraft with a cruise speed in excess of approximately Mach 2 are unlikely to mature enough to enable operational deployment of an environmentally acceptable, economically viable Mach 2+ commercial supersonic aircraft during the next 25 years.

The ultimate importance of the commercial supersonic aircraft to the U.S. air transportation system is expounded in the long-range technology plans and visions of NASA, the Department of Transportation, and the National Science and Technology Council. Fulfilling these visions of the future will require a long-term investment strategy that looks beyond the short-term economic factors that drive much industry-funded research. The importance of a long-term view is especially important with breakthrough technologies. Unfortunately, both government and industry are reluctant to make the long-term investments necessary to mature expensive, high-risk technologies. In particular, at a time when manufacturers require TRLs of 6 or higher to embrace complex new technologies in safety-critical aeronautics applications, NASA appears to be changing its technology investment strategy so that it reaches TRLs of only 3 or 4. The likely result is a technology maturation gap that could jeopardize U.S. leadership in aerospace technology. To avoid this result—that is, to allow promising technologies to make the transition from the laboratory to the marketplace—NASA must invest enough to achieve TRL 6. With past programs,

such as the HSR Program, NASA adopted TRL 6 as the appropriate goal for commercial supersonic research, and the committee is concerned that NASA's less ambitious goals for much of its ongoing aeronautics research is driven more by the need to curtail aeronautics research because of reduced funding than by an objective assessment of what it will take to achieve the government's programmatic goals.

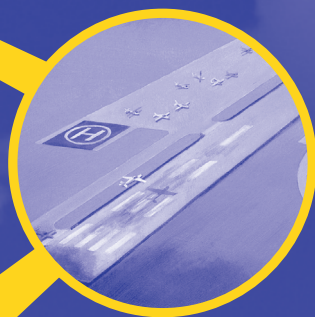
Recommendation 3. NASA and other federal agencies should advance the technologies listed in Findings 1 and 2 and Recommendations 1 and 2 to technology readiness level 6 to make it reasonably likely that they will lead to the development of a commercial product.

In summary, the committee identified no insurmountable obstacles to the development of commercial supersonic aircraft and believes that a properly focused research effort by NASA could develop technological solutions to the key problems identified in Finding 1, thereby enabling a successful commercial development program by industry in the relatively near term, especially for aircraft with a cruise speed of less than Mach 2.0. Without continued effort, however, an economically viable, environmentally acceptable commercial supersonic aircraft is likely to languish. National indifference to supersonic technology development would jeopardize longstanding U.S. supremacy in the aviation business segment and significantly harm the nation's economy. The United States is not the only sponsor of supersonic technology development, and once a commercial supersonic aircraft is developed, users in the United States and other countries will purchase it, regardless of where it is manufactured.

SPECIAL REPORT 263

Future Flight

**A Review of the Small Aircraft
Transportation System Concept**



Transportation Research Board
THE NATIONAL ACADEMIES

Executive Summary

The Small Aircraft Transportation System (SATS) program has been established by the Office of Aerospace Technology in the National Aeronautics and Space Administration (NASA). In the initial 5-year phase of the program, NASA is working with the private sector and university researchers, as well as other federal and state governmental agencies, to further various aircraft-based technologies that will

- Increase the safety and utility of operations at small airports lacking traffic control towers, radar surveillance, or other conventional ground-based means of monitoring and safely separating aircraft traffic in the terminal airspace and on runways and taxiways;
- Allow more dependable use of small airports lacking instrument landing systems or other ground-based navigation systems that are now required for many nighttime and low-visibility landings; and
- Improve the ability of single-piloted aircraft to operate safely in complex airspace (that is, at airports and in airways with many and diverse operators).

Guiding this program is a longer-range SATS vision of the routine use of advanced, small fixed-wing aircraft—of a size common in general aviation (GA) (4 to 10 passengers)—for personal transportation between small communities. NASA envisions tens of thousands of advanced small aircraft being used in this role. Key to this guiding vision are advances anticipated by NASA in technologies and processes that will make small aircraft much less expensive to produce, maintain, and operate; more environmentally acceptable; and much easier, safer, and more reliable to fly than are small GA aircraft today.

NASA envisions that such a transportation system, once developed and deployed, could reduce congestion and delays in the commercial aviation sector by diverting passenger traffic from large airports and could improve transportation service in many more communities by making better use of the nation's small airports and least-traveled airways. Currently, NASA's SATS technology research program is being justified on the basis of these anticipated benefits and the expectation that major challenges to the development and deployment of such a system—from technological and economic considerations to safety and environmental requirements—can be met.

NASA asked the Transportation Research Board to convene a study committee to review the plausibility and desirability of the SATS concept, giving special

consideration to whether its potential net benefits—from user benefits to overall environmental and safety effects—are sufficiently promising to warrant public-sector investment in SATS development and deployment (see Box P-1 of the Preface for the statement of task). The absence of credible examinations of SATS by NASA compelled the committee to undertake its own analyses of the concept's plausibility and desirability, which are presented in Chapter 4. The committee's conclusions and advice derived from these analyses are provided in detail in Chapter 5; they are summarized in the following paragraphs.

The committee does not share NASA's vision for SATS, nor does the committee support the use of this vision to guide technology development and deployment investments. Numerous findings, summarized below, suggest that such a system is neither likely to emerge as conceived nor to contribute substantially to satisfying travel demand. Nevertheless, the committee endorses NASA's efforts to develop and demonstrate technologies that can help further the highly desirable outcomes listed in the three bullets above. To help achieve these outcomes, the committee urges NASA to prioritize, without regard to the SATS concept, the capabilities and technologies now being pursued in the 5-year program according to a clearly delineated set of civil aviation needs (such as improved GA safety) that these new capabilities and technologies can help meet.

NASA has a traditional and vital role in advancing aeronautics technologies that can enhance civil aviation safety, capacity, accessibility, and environmental compatibility. Technological capabilities to reduce the probability of air traffic conflicts in more places, permit more reliable and safe operations during inclement weather at more airports, and enhance the safety of single-pilot operations could improve the safety and utility of the nation's civil aviation system. The full-scale SATS concept, however, should not be used to guide the R&D program because it presents an unlikely and potentially undesirable outcome. Analyses of the concept suggest the following:

- Limited potential for the use of SATS aircraft to be affordable by the general public. The aircraft envisioned for SATS would need to be far more advanced and sophisticated than even the highest-performing small GA aircraft of today to achieve the standards of safety, ease of use and maintenance, and environmental friendliness that would attract large numbers of users. The committee found no evidence to suggest that such aircraft could be made affordable for use by large numbers of people and businesses.
- Limited potential for SATS to attract large numbers of users because of its orientation to travel markets outside the nation's major metropolitan areas. Most people and businesses are located in metropolitan areas, which are the origins and destinations of most time-sensitive business travelers and most intercity passenger trips overall. The expectation that large numbers of people will use advanced small aircraft to fly between airports in small, nonmetropolitan communities runs counter to long-standing travel patterns and demographic and economic trends.
- Limited appeal to price-sensitive leisure travelers, who use the automobile for most short or medium-length intercity trips. Most intercity travelers are highly sensitive to the price of travel, especially in the short- to medium-length trip markets

envisioned for SATS. Leisure travelers, who account for the majority of all intercity trips under 1,000 miles, usually travel by automobile, largely because of the versatility it offers and the low additional cost per passenger.

- Significant obstacles to SATS deployment because of infrastructure and ancillary service limitations at small airports, as well as potential environmental concerns at such airports, including increases in aircraft noise and air pollutant emissions. Most of the country's 5,000 public-use airports have minimal infrastructure and support services, which limits their suitability for frequent and routine transportation usage. About half of all public-use airports have a paved runway that is at least 4,000 feet long and thus potentially capable of handling small jet aircraft; yet, most of these airports would likely require further infrastructure investments.

- The implausibility of expeditious and nonevolutionary deployment of SATS technologies because of technical challenges and the need for high levels of safety assurance that have been notably neglected in the SATS program. Safety is paramount in aviation, particularly for passenger transportation. Hence, any changes in aviation, from new methods of air traffic control and pilot training and certification procedures to new aircraft materials and manufacturing processes, are subject to intense and thorough safety evaluations and validations that can take much time. The idea that many nonevolutionary changes in aircraft design, propulsion, flight control, communications, navigation, surveillance, and manufacturing techniques could emerge at about the same time and be accepted as safe by users, manufacturers, insurers, and regulators is highly questionable.

- A genuine potential for many undesirable congestion, safety, and environmental effects from SATS deployment. If SATS does not access major metropolitan markets, it will likely have little, if any, meaningful effect on operations at the nation's busiest and most capacity-constrained large airports, where most delays in the commercial air transportation system occur. Yet, if SATS does access these markets, the mixing of SATS with non-SATS aircraft in heavily used, controlled airspace and airports could create significant traffic management challenges. Moreover, a well-used SATS could have negative net effects on aviation's environmental compatibility by shifting travelers from larger aircraft, each carrying dozens of travelers, to smaller aircraft, each carrying a handful of travelers.

More generally, the committee believes that positing any such preconceived system, in which a single and definitive vehicle concept is used to guide research and development, could inhibit the evolution of alternative outcomes that may result from technological opportunities and economic and social needs. The heightened emphasis on aviation security in recent months (discussed in the Afterword to this report) is an example of how difficult it is to accurately predict change in the aviation sector. NASA's strength in civil aeronautics is in technology research and development, and not in defining, developing, and promoting new transportation systems.

Although it does not share NASA's vision for SATS, the committee commends NASA for using its resources and expertise to leverage and stimulate private-sector investment in civil aeronautics research and development. Indeed, it is essential that NASA researchers work closely with commercial developers and users, since the private sector understands the current market for technologies and can provide

guidance on applications that appear likely. Furthermore, NASA must seek the active involvement of the Federal Aviation Administration (FAA) and state and local agencies in the technology program. Their involvement is necessary in reaching an understanding of the constraints on technology deployment, such as environmental, safety, and public finance concerns.

To ensure the continuation of forward-looking aeronautics R&D, **the committee urges NASA to join with other relevant government agencies, led by the Department of Transportation, in undertaking studies of future civil aviation needs and the opportunity for technology advancements to meet them and potentially stimulate new uses for civil aviation.** Working with FAA, the National Transportation Safety Board, and other governmental agencies with operational and technological expertise should give NASA a better understanding of such needs and opportunities. The capabilities and technologies being developed under the SATS program may prove useful in ways that are not now apparent; for instance, they may benefit many different users by increasing the safety and utility of both general and commercial aviation. Indeed, many system and vehicle configurations that are not envisioned for the current SATS concept may prove useful. The committee urges NASA to keep such possibilities in mind.

The committee commends NASA for requesting and sponsoring this review, which offers the opportunity for the perspectives and advice of experts in transportation and other disciplines not involved in the conception of SATS to be brought to bear. Such external reviews are a valuable means of obtaining fresh perspectives on R&D program goals, plans, and accomplishments, and additional policy-level and technical reviews are desirable as the restructured program proceeds.



FINAL REPORT

of the Commission on the Future of the United States Aerospace Industry



ANYONE



ANYTHING

ANYTIME



ANYWHERE



November, 2002

Executive Summary

Aerospace will be at the core of America's leadership and strength in the 21st century. The role of aerospace in establishing America's global leadership was incontrovertibly proved in the last century. This industry opened up new frontiers to the world, such as freedom of flight and access to space. It provided products that defended our nation, sustained our economic prosperity and safeguarded the very freedoms we commonly enjoy as Americans. It has helped forge new inroads in medicine and science, and fathered the development of commercial products that have improved our quality of life.

Given a continued commitment to pushing the edge of man's engineering, scientific and manufacturing expertise, there is the promise of still more innovations and new frontiers yet to be discovered. It is imperative that the U.S. aerospace industry remains healthy to preserve the balance of our leadership today and to ensure our continued leadership tomorrow.

Our Urgent Purpose

The contributions of aerospace to our global leadership have been so successful that it is assumed U.S. preeminence in aerospace remains assured. Yet the evidence would indicate this to be far from the case. The U.S. aerospace industry has consolidated to a handful of players—from what was once over 70

suppliers in 1980 down to 5 prime contractors today. Only one U.S. commercial prime aircraft manufacturer remains. Not all of these surviving companies are in strong business health. The U.S. airlines that rely upon aerospace products find their very existence is threatened. They absorbed historical losses of over \$7 billion in 2001 and potentially more this year.

The Commission's urgent purpose is to call attention to how the critical underpinnings of this nation's aerospace industry are showing signs of faltering—and to raise the alarm.

The industry is confronted with a graying workforce in science, engineering and manufacturing, with an estimated 26 percent available for retirement within the next five years. New entrants to the industry have dropped precipitously to historical lows as the number of layoffs in the industry mount. Compounding the workforce crisis is the failure of the U.S. K-12 education system to properly equip U.S. stu-

dents with the math, science, and technological skills needed to advance the U.S. aerospace industry.

The Commission's urgent purpose is to call attention to how the critical underpinnings of this nation's aerospace industry are showing signs of faltering—and to raise the alarm.

This nation has generously reaped the benefits of prior innovations in aerospace, but we have not been attentive to its health or its future. During this year of individual and collective research, the Commission has visited and spoken with aerospace

leaders in the United States, Europe, and Asia. We noted with interest how other countries that aspire for a great global role are directing intense attention and resources to foster an indigenous aerospace industry. This is in contrast to the attitude present here in the United States. We stand dangerously close to squandering the advantage bequeathed to us by prior generations of aerospace leaders. We must reverse this trend and march steadily towards rebuilding the industry.

The time for action is now. This report contains recommendations intended to catalyze action from leaders in government, industry, labor and academia and assure this industry's continued prominence. A healthy aerospace industry is a national imperative. The Administration and the Congress must heed our warning call and act promptly to implement the recommendations in this report.

An Aerospace Vision

This nation needs a national vision to keep alive the flames of imagination and innovation that have always been a hallmark of aerospace. For inspiration, we looked to what aerospace can do for our nation and world. The vision the Commission used to guide its efforts is “Anyone, Anything, Anywhere, Anytime.” We offer this to the nation as its vision for aerospace.

Conclusions and Recommendations

The Congress gave our Commission a broad mandate to study the health of the aerospace industry and to identify actions that the United States needs to take to ensure its health in the future. The challenge of looking across military, civil and commercial aspects of aviation and space was an opportunity to take an integrated view of the aerospace sector – government, industry, labor and academia.

The Commissioners represent a broad cross section of the stakeholders responsible for the health of the industry and whose expertise represents the breadth and depth of aerospace issues. Drawing on their

extensive experience, and on the hundreds of briefings and public testimony, the Commission has made nine recommendations—one per chapter—that provide our guidance to the nation's leaders on the future of the U.S. aerospace industry. The size and scope of this report reflects an industry that is complex and interdependent.

The following are the conclusions and recommendations in the final report by chapter.

*VISION: “Anyone,
Anything, Anywhere,
Anytime.”*

Chapter 1—Vision: Anyone, Anything, Anywhere, Anytime

Conclusions

To achieve our vision for aerospace, the Commission concludes that:

- The nation needs a national aerospace policy;
- There needs to be a government-wide framework that implements this policy;
- The Administration and Congress need to remove prohibitive legal and regulatory barriers that impede this sector's growth and continually seek to level the international playing field; and
- Global U.S. aerospace leadership can only be achieved through investments in our future, including our industrial base, workforce, long-term research and national infrastructure.

Recommendation #1

The integral role aerospace plays in our economy, our security, our mobility, and our values makes global leadership in aviation and space a national imperative. Given the real and evolving challenges that confront our nation, government must commit to increased and sustained investment and must facilitate private investment in our national aerospace sector. The Commission, therefore, recommends that the United States boldly pioneer new frontiers in aerospace technology, commerce and exploration.

Chapter 2—Air Transportation: Exploit Aviation's Mobility Advantage

Conclusions

The Commission concludes that superior mobility afforded by air transportation is a huge national asset and competitive advantage for the United States. Because of the tremendous benefits derived from a highly mobile citizenry and rapid cargo transport, the United States must make consistent and significant improvements to our nation's air transportation system a top national priority.

TRANSFORM THE U.S. AIR TRANSPORTATION SYSTEM AS A NATIONAL PRIORITY. We need national leadership to develop an air transportation system that simultaneously meets our civil aviation, national defense and homeland security needs. Today, leadership and responsibility are dispersed among many federal, state and local organizations that impact the aviation community. In the federal government, this includes the Department of Transportation's Federal Aviation Administration (FAA), National Aeronautics and Space Administration (NASA), Environmental Protection Agency, and the Departments of Defense (DoD), Commerce, and State.

Often these departments and agencies deal with aviation-related issues independently, without adequate coordination, and sometimes at cross-purposes. All have separate authorizing and appropriating Congressional committees. State and local governments also play important aviation development roles and private industry has numerous near-term competing forces that often delay longer-term solutions. Only strong federal leadership, aimed at a national objective, can sustain a transformational effort.

DEPLOY A NEW, HIGHLY AUTOMATED AIR TRAFFIC MANAGEMENT SYSTEM. The core of an integrated 21st century transportation system will be a common advanced communications, navigation and surveillance infrastructure and modern operational procedures. The system needs to allow all classes of aircraft, from airlines to unpowered vehicles, to operate safely, securely, and efficiently from thousands of communities based on market size and demand. It

also needs to be able to operate within a national air defense system and enable military and commercial aircraft to operate around the world in peacetime and in war.

As a first step, the Commission recommended in its Interim Report #2 "the Administration should immediately create a multi-agency task force with the leadership to develop an integrated plan to transform our air transportation system." This task force should be immediately assigned the leadership role to establish a Next Generation Air Transportation System Joint Program Office that brings together needed participation from the FAA, NASA, DoD, Office of Homeland Security, National Oceanographic and Atmospheric Administration, and other government organizations. Within a year, the Joint Program Office should present a plan to the Administration and the Congress outlining the overall strategy, schedule, and resources needed to develop and deploy the nation's next generation air transportation system.

As this transformational plan is developed, the FAA must continue to implement the Operational Evolution Plan. FAA and NASA must also continue to perform critical long-term research. The Commission also recommended in Interim Report #2 "the Administration and Congress should fully fund air traffic control modernization efforts in fiscal year 2003 and beyond, and prioritize FAA and NASA research and development efforts that are the critical building blocks for the future."

PROVIDE CERTIFICATION PROCESS AND AIRBORNE EQUIPAGE INNOVATION. The Commission calls for a new approach to the regulation and certification of aircraft technology, processes and procedures. The government also needs new mechanisms to accelerate the equipage of aircraft in order for the nation to realize broader system benefits. Airborne equipment needed for safe, secure, and efficient system-wide operations should be deemed to be part of the national aviation infrastructure.

- *Shift from product to process certification.* Instead of a focus on rules and regulations that dictate the

design and approval of each particular piece of hardware or software, the FAA should focus on certifying that design organizations have safety built into their processes for designing, testing, and assuring the performance of an overall system.

- *Solve the airborne equipage problem.* The government, in partnership with industry, must be more responsible for airborne equipment development and continuous modernization. In addition to current regulatory and operational incentives, the government should consider additional options to motivate a critical mass of early equippers, including full federal funding for system-critical airborne equipment, tax incentives or vouchers for partial funding support, and competitively auctioned credit vouchers.

STREAMLINE THE AIRPORT AND RUNWAY DEVELOPMENT PROCESS. The FAA and other agencies should expedite new runway and airport development as a national priority. Further, because aircraft noise and emissions constrain capacity growth, additional government investment in long-term research in this area is imperative.

ACT NOW. The Commission sees compelling reasons for the Administration and Congress to take immediate action. First, new homeland security and defense requirements call for system capabilities not previously anticipated. Second, an entirely new level of transportation efficiency and national mobility can be enabled by more flexible, scalable, higher precision aviation operations. Third, inherently long lead times required for major aviation changes demand preparation far ahead of anticipated demand. And fourth, there could be no better American response after 9/11 than to rebuild the U.S. air transportation system dramatically better than it was before.

As we approach the 100th anniversary of powered flight, the Commission urges the President and Congress to recognize a pressing national need, and powerful opportunity, and **act now** to create a 21st century air transportation system.

Recommendation #2

The Commission recommends transformation of the U.S. air transportation system as a national priority. This transformation requires:

- Rapid deployment of a new, highly automated air traffic management system, beyond the Federal Aviation Administration's Operational Evolution Plan, so robust that it will efficiently, safely, and securely accommodate an evolving variety and growing number of aerospace vehicles and civil and military operations;
- Accelerated introduction of new aerospace systems by shifting from product to process certification and providing implementation support; and
- Streamlined new airport and runway development.

Chapter 3—Space: Its Special Significance

Conclusions

The Commission concludes that the nation will have to be a space-faring nation in order to be the global leader in the 21st century—our freedom, mobility, and quality of life will depend on it. America must exploit and explore space to assure national and planetary security, economic benefit and scientific discovery. At the same time, the United States must overcome the obstacles that jeopardize its ability to sustain leadership in space.

ACHIEVE BREAKTHROUGHS IN PROPULSION AND SPACE POWER. The ability to access space and travel through the solar system in weeks or months instead of years would help create the imperative to do so. Propulsion and power are the key technologies to enable this capability. Future progress in these areas will result in new opportunities on Earth and open the solar system to robotic and human exploration and eventual colonization. The nation would benefit from a joint effort by NASA and DoD to reduce significantly the cost and time required to access and travel through space.

DEVELOP A NEXT GENERATION COMMUNICATION, NAVIGATION, SURVEILLANCE AND RECONNAISSANCE CAPABILITY. The nation needs real-time, global space-based communications, navigation, surveillance and reconnaissance systems for a wide range of applications. These capabilities will provide the military with the ability to move its forces around the world, conduct global precision strike operations, defend the homeland, and provide for planetary defense. The civil and commercial sectors will also benefit from these capabilities for air transportation management, monitoring global climate change, weather forecasting and other applications. The federal government needs a joint civil and military initiative to develop this core infrastructure.

REVITALIZE THE U.S. SPACE LAUNCH INFRASTRUCTURE. NASA and DoD must maintain and modernize their space launch and support infrastructure to bring them up to industry standards. They should implement our recommendations contained in Interim Report #3 concerning federal spaceports, enhanced leasing authority, and utility privatization and “municipalization.” We recommended that DoD and NASA should:

- Investigate the feasibility of establishing a national spaceport structure at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS) under a single management system; and
- Seek Congressional approval for
 - Enhanced leasing authority that allows them to lease real property at fair market value and retain lease proceeds to cover the total costs incurred at KSC and CCAFS; and
 - Privatization of NASA utilities at KSC and CCAFS to overcome the budget burdens associated with capital improvements to outdated infrastructure.

In addition, NASA and DoD need to make the investments necessary for developing and supporting future launch capabilities. NASA should also consider turning over day-to-day management responsibilities for its field centers to the respective state governments, universities, or companies.

PROVIDE INCENTIVES TO COMMERCIAL SPACE. Government and the investment community must become more sensitive to commercial opportunities and problems in space. Public space travel may constitute a viable marketplace in the future. It holds the potential for increasing launch demand and improvements in space launch reliability and reusability. Moreover, it could lead to a market that would ultimately support a robust space transportation industry with “airline-like operations.” The government could help encourage this by allowing NASA to fly private citizens on the Space Shuttle.

SUSTAIN COMMITMENT TO SCIENCE AND SPACE. The U.S. government should continue its long-standing commitment to science missions in space and focus on internationally cooperative efforts in the future.

Recommendation #3

The Commission recommends that the United States create a space imperative. The DoD, NASA, and industry must partner in innovative aerospace technologies, especially in the areas of propulsion and power. These innovations will enhance our national security, provide major spin-offs to our economy, accelerate the exploration of the near and distant universe with both human and robotic missions, and open up new opportunities for public space travel and commercial space endeavors in the 21st century.

Chapter 4—National Security: Defend America and Project Power

Conclusions

The Commission concludes that aerospace capabilities and the supporting defense industrial base are fundamental to U.S. economic and national security. While the nation’s defense industrial base is strong today, the nation is at risk in the future if the United States continues to proceed without a policy that supports essential aerospace capabilities.

DEVELOP A U.S. MILITARY INDUSTRIAL BASE POLICY. The Department of Defense should task the Defense Science Board to develop a national policy that

will invigorate and sustain the U.S. aerospace industrial base. The policy should address issues, such as mergers and acquisitions, procurement and budgeting policies, research and development investments, technology transition, international sales and workforce development.

SUSTAIN THE DEFENSE INDUSTRIAL BASE. Today's national defense industrial base is indeed robust, but without constant vigilance and investment, vital capabilities will be lost.

- DoD's annual science and technology (6.1-6.3) funding must be sufficient and stable to create and demonstrate the innovative technologies needed to address future national security threats. An amount no less than three percent of Total Obligational Authority, "fenced" from budget cuts, would be sufficient. The use of more joint technology development and acquisition programs would spread the funding burden and promote interoperability.
- The federal government must remove unnecessary barriers to international sales of defense products, and implement other initiatives that strengthen transnational partnerships to enhance national security. To help reduce the high development and production costs of advanced military systems, the United States must also increase the number of international joint programs (like the Joint Strike Fighter), and continue to foster international interoperability of defense and commercial aerospace system-of-systems.
- DoD acquisition policies should be revised to encourage greater use of commercial standards. DoD should impose government requirements by exception only, allow commercial entities to protect intellectual property, and remove other burdensome regulations that deter providers of commercial products from doing business with the government.
- There are numerous government missions that would benefit from defense technology. For example, the U.S. military has developed capabilities

in the areas of communications, navigation, surveillance, and reconnaissance. These technologies could be adapted and transitioned into other government applications that would significantly enhance the capacity of our air traffic management system and, hence, our national defense and homeland security.

- The federal government and the aerospace industry must partner to enhance the operational readiness and capability of new and legacy military aerospace systems. The government should fund research and technology development programs to: reduce total ownership costs and environmental impacts; implement performance-based logistics support; create a structured, timely and adequately funded technology insertion process; and reform its procurement practices accordingly.

INCREASE OPPORTUNITIES TO GAIN EXPERIENCE IN THE WORKFORCE. The U.S. must continuously develop new experimental systems, with or without a requirement for production, in order to sustain the critical skills to conceive, develop, manufacture and maintain advanced systems and potentially provide expanded capability to the warfighter. Furthermore, the federal government and industry must develop approaches to retain and transfer intellectual capital as the workforce retires in greater numbers in the next few years.

MAINTAIN AND ENHANCE CRITICAL NATIONAL INFRASTRUCTURE. The federal government must assume responsibility for sustaining, modernizing, and providing critical, often high-risk, defense-related technologies and infrastructure when it is in the nation's interest. This includes critical design capabilities, solid rocket boosters, radiation hardening, space launch facilities, critical research, development, test and evaluation (RDT&E) infrastructure, Global Positioning System (GPS), and frequency spectrum.

Recommendation #4

The Commission recommends that the nation adopt a policy that invigorates and sustains the

aerospace industrial base. This policy must include:

- Procurement policies which include prototyping, spiral development, and other techniques which allow the continuous exercise of design and production skills;
- Removing barriers to defense procurement of commercial products and services;
- Propagating defense technology into the commercial sector, particularly in communications, navigation and surveillance;
- Removing barriers to international sales of defense products;
- Sustaining critical technologies that are not likely to be sustained by the commercial sector, e.g. space launch, solid boosters, etc.; and
- Stable funding for core capabilities, without which the best and brightest will not enter the defense industry.

Chapter 5—Government: Prioritize and Promote Aerospace

Conclusions

The Commission concludes that the government must ensure that the nation has a healthy aerospace industry today and in the future, an industry that can not only meet the security and economic needs of the country but also can compete successfully in the international market place. The government needs to exert leadership and prioritize and promote aerospace by managing its activities efficiently, effectively and as a sector to accomplish national objectives. It needs to create an environment that fosters innovation in the U.S. aerospace industry, ensuring its competitiveness into the 21st century.

CREATE A NATIONAL AEROSPACE CONSENSUS. The federal government does not have a national aerospace consensus that supports broader national security and economic policies, goals and objectives. This will require Presidential and Congressional leadership to develop a consensus of federal, state and local

government, industry, labor, academia and non-governmental organizations to sustain a healthy U.S. aerospace sector.

REORIENT GOVERNMENT ORGANIZATIONAL STRUCTURES. The federal government is dysfunctional when addressing 21st century issues from a long-term, national and global perspective. Government is organized vertically while national problems are becoming more horizontal in nature requiring system-of-systems solutions. Key government processes, such as planning and budgeting, are currently spread across multiple departments and agencies, with oversight by numerous Congressional committees. As a result, none of these government groups has an integrated view of our national aerospace efforts.

The executive and legislative branches need to be reoriented to provide a focus on national aerospace needs and priorities, government aerospace plans and budgets, and government management of national aerospace initiatives.

- *Federal Departments and Agencies.* Every federal department and most federal agencies should create an Office of Aerospace Development to prioritize and promote aerospace activities within their organizations and with the public that they serve;
- *Office of Management and Budget (OMB).* OMB should establish a Bureau of Aerospace Management to develop and implement an aerospace strategic plan, establish an acceptable categorical definition of the aerospace sector, prepare an annual aerospace sector budget as an addendum to the President's Budget Request, and manage major national aerospace initiatives; and,
- *White House.* The White House should establish an aerospace policy coordinating council to develop and implement national aerospace policy consistent with national security and economic goals and objectives.
- *Congress.* In response to these executive branch changes, the Commission encourages the legislative branch to create a Joint Committee on

Aerospace to coordinate legislatively the multifaceted jurisdictional issues.

STREAMLINE AND INTEGRATE KEY GOVERNMENT PROCESSES. Government processes for policy, planning, and budgeting, and for developing and acquiring aerospace products and services are vestiges of the Cold War. As a result, they tend to be ad hoc, complex, lengthy and inefficient. The Administration and the Congress need to make a concerted effort to streamline these key government processes to reflect the new realities of a highly dynamic, competitive and global marketplace. Specifically, they should work together to create: an integrated federal planning, budgeting and program management process; an integrated government science, technology and acquisition process; and an environment that fosters rather than impedes innovation in the aerospace sector.

PROMOTE PRIVATE-PUBLIC PARTNERSHIPS. Partnerships and interconnectedness are keys to competitiveness in the future. Government, industry, labor and academia play different, but important, roles in developing and deploying new aerospace products and services. They cannot perform these roles separately and in isolation. But today, cultural and institutional biases hinder their ability to partner and achieve national goals. We need to create an environment and the incentives that will foster private-public partnerships.

Recommendation #5

The Commission recommends that the federal government establish a national aerospace policy and promote aerospace by creating a government-wide management structure. This would include a White House policy coordinating council, an aerospace management office in the OMB, and a joint committee in Congress. The Commission further recommends the use of an annual aerospace sectoral budget to establish presidential aerospace initiatives, assure coordinated funding for such initiatives, and replace vertical decision-making with horizontally determined decisions in both authorizations and appropriations.

Chapter 6—Global Markets: Open and Fair

Conclusions

Open global markets are critical to the continued economic health of U.S. aerospace companies and to U.S. national security. In order to remain global leaders, U.S. companies must remain at the forefront of technology development. They must also have access to global customers, suppliers and partners in order to achieve economies of scale in production needed to integrate that technology into their products and services.

Government intervention continues to distort global markets, from subsidies to anti-competitive restrictions on partnerships and collaboration to biased standards and regulations. U.S. companies frequently find themselves competing against foreign competitors supported directly or indirectly by their governments. We need to move to a different model of business characterized by competition between companies instead of between countries.

REFORM EXPORT CONTROLS AND DEFENSE PROCUREMENT POLICIES. U.S. national security and procurement policies represent some of the most burdensome restrictions affecting U.S. industry competitiveness.

We call for a fundamental shift away from the existing transaction-based export-licensing regime to process-based licensing. Under this new system, the government would rely on companies to safeguard against the sale of controlled technologies to unacceptable parties through internal company controls certified by the government. The government then would monitor and audit those company operations for compliance. Such a process-based licensing regime would improve security, reduce licensing costs and enable our companies to collaborate with international partners and sell to global customers.

Additional reforms, including those outlined in Interim Report #2, are necessary to make this new system effective. As quickly as possible, the government should revise the U.S. Munitions List,

remove barriers to global project licenses, expand waivers for trading with friendly nations, and update country risk surveys to facilitate better policy decisions.

U.S. procurement regulations currently are too restrictive and must be modified to be supportive of a global industrial base to meet military requirements, while maintaining U.S. industrial capacity in critical technologies and capabilities. We need to reform DoD procurement regulations to permit integration of commercial components into military products even if they are provided by non-U.S. companies or worked on by foreign nationals.

ESTABLISH A LEVEL INTERNATIONAL “PLAYING FIELD”.

U.S. companies have lost market share to foreign companies supported by protectionist and market distorting policies. The U.S. government must take immediate action to neutralize these distortions and enable fair and open competition.

We must continue to meet our responsibilities of setting national goals and priorities for basic research, reverse declines in basic research and experimentation funding and expand efforts to fund technology diffusion through U.S. industry.

We also must work bilaterally and multilaterally to get foreign governments out of the business of commercial “product launch.” In spite of inadequacies of the current World Trade Organizations (WTO) system, the U.S. government should work in the WTO Doha round of negotiations to strengthen the existing WTO provisions restricting the use of subsidies to distort the market. The U.S. government also should work with other WTO members to adopt more effective trade remedies that are usable and effective in a market characterized by increased globalization. When countries do violate existing provisions, we should not shy away from taking action.

We must ensure that U.S. companies are not disadvantaged by differences between U.S. and foreign tax policies as exemplified in the current WTO dispute over U.S. Foreign Sales Corporation/Extra Territorial Income regulations. In the near term we

must seek to delay European trade sanctions while both parties negotiate a solution to this dispute. We urge the Administration and Congress to authorize changes to U.S. tax law that are WTO compliant but that continue to offset the advantage enjoyed by European companies. In the longer term, the Administration should initiate changes in the WTO rules to remove the current inequity in the treatment of direct and indirect taxes that caused the dispute in the first place.

Official export credit support for commercial and military products is an essential tool to facilitate U.S. aerospace exports. In addition to continued funding for U.S. Export-Import Bank programs, we should seek to reduce international reliance on official export credits for export financing assistance, such as through ratification of the “Cape Town convention.” For military exports, the Defense Export Loan Guarantee should be modernized to permit the DoD to create an effective unsubsidized export credit organization to facilitate the financing of defense exports to U.S. allies and friendly nations abroad.

The U.S. government should remove policy and regulatory obstacles to increased commercial mergers and teaming within the U.S. and with international partners. The U.S. government should assist in developing and policing international anti-trust treaties relating to mergers and teaming between commercial entities to minimize divergence of requirements and the methods of assessment in anti-trust reviews, presumably making reviews more objective. The U.S. government also must continue to work bilaterally with key countries to remove barriers to foreign investment.

Global standards and regulations are critical to the efficient operation of the global aviation system and international markets. The U.S. government needs to step up its commitment to the development of global standards in International Civil Aviation Organization (ICAO) and via other forums. This will help to mitigate the efforts of other countries seeking to provide a competitive advantage for their companies through biased domestic standards or regulations.

COMMIT TO GLOBAL PARTNERSHIPS. International partnerships are essential to the creation of system-of-systems solutions to global challenges.

In order to meet our goal of transforming the way we use airspace through the use of advanced technology and improved procedures, we must act in concert with other countries around the world. We must commit to developing common standards and recommended practices for satellite navigation in ICAO, and ensure that global cooperative efforts are not thwarted by disputes over radio spectrum allocation. We strongly urge U.S. officials to work bilaterally and multilaterally to ensure that U.S. GPS and European Galileo systems are compatible and complementary in the event that Galileo becomes a reality.

U.S. policy makers should work toward global standards for safety certification as a way to prevent the use of safety certification by some governments to enhance their domestic competitiveness. We also call for increased liberalization of air transport services through negotiation of open skies agreements in order to expand the demand for all countries' air transport services and alleviate undue congestion at the largest airports.

The success or failure of our future activities in space is fundamentally linked to our ability to work effectively with international partners. It is in our country's best interest to work cooperatively with partner nations in space exploration and protection of our planet from the threat of near-earth objects.

Recommendation #6

The Commission recommends that U.S. and multi-lateral regulations and policies be reformed to enable the movement of products and capital across international borders on a fully-competitive basis, and establish a level playing field for U.S. industry in the global market place. U.S. export control regulations must be substantially overhauled, evolving from current restrictions on technologies through the review of transactions to controls on key capabilities enforced through process controls. The U.S.

government should neutralize foreign government market intervention in areas such as subsidies, tax policy, export financing and standards, either through strengthening multilateral disciplines or providing similar support for U.S. industry as necessary.

Chapter 7—Business: A New Model for the Aerospace Sector

Conclusions

The Commission concludes that for our aerospace industry to be globally preeminent, now and in the future, it must be able to attract vitally needed capital at a reasonable cost. We further conclude that the defense and aerospace sector is viewed as a low growth industry with low margins, unstable revenue and a capricious major customer, the government. Without a significant change in the business model, the future of the aerospace industry, so critical to our national economic and homeland security, is uncertain and at risk.

PROVIDE INVESTMENT OPPORTUNITIES. Predictability, stability and performance are critical to the health and growth of a robust aerospace industry. The government must stabilize program requirements and protect adequate long-term investment funding, enact reforms that increase the financial flexibility of industry and the government, and improve program management stability.

ENABLE INDUSTRY TO ATTRACT AND RETAIN HIGH-TECH PARTNERS AND SUPPLIERS. The future of the aerospace industry is intrinsically tied to the ability of the sector to attract and retain high-tech partners and suppliers throughout the supply chain. The government should pursue near-term reforms to realign purchasing processes to lower costs and gain access to new technology by eliminating, or at least lowering, barriers that make government business inefficient and unattractive to commercial firms. DoD should implement changes to permit greater profitability and financial flexibility of industry working on government efforts. A government-wide review of functions and services should be conducted to

identify those functions that are not “core” to the effective operation of government and those functions that could best be performed by the private sector.

CREATE A FAVORABLE DOMESTIC AND INTERNATIONAL BUSINESS CLIMATE. Certain U.S. tax and trade laws and regulations that affect a wide variety of industries weigh particularly heavily on defense and aerospace, both in competition with domestic commercial entities as well as in the international markets. The government should act promptly to replace burdensome tax laws and outdated trade laws with laws and regulations that remove unnecessary administrative burdens from industry and recognize the unique contribution of defense and aerospace companies to our nation’s defense and economic security. In addition, the Administration and Congress should review and consider reducing user fees on the airlines and their customers.

ENSURE LONG-TERM GROWTH AND FINANCIAL HEALTH. Government and industry must recognize that a healthy, competitive, and innovative industry meeting security and aerospace needs must be closely integrated with the global commercial marketplace. Major challenges to this desired climate include the need for dramatic personnel and training reform and recognition of the dynamic interrelated global environment. Government and industry should work together to develop and implement training and exchange programs that would educate and expose their workforces to those challenges and responsibilities. All government officials with budget and program acquisition, management, or review responsibilities, both appointed and elected, should be required to have a business or financial background or training. Finally, government must develop and implement a policy regarding international cooperation in defense and aerospace that recognizes the global industrial base. The Administration is urged to undertake a review of the current policy regarding both domestic and international business combinations, based on an analysis of the U.S. defense industrial base, including the supplier industrial base.

Recommendation #7

The Commission recommends a new business model, designed to promote a healthy and growing U.S. aerospace industry. This model is driven by increased and sustained government investment and the adoption of innovative government and industry policies that stimulate the flow of capital into new and established public and private companies.

Chapter 8—Workforce: Launch the Future

Conclusions

Clearly, there is a major workforce crisis in the aerospace industry. Our nation has lost over 600,000 scientific and technical aerospace jobs in the past 13 years. These layoffs initially began as a result of reduced defense spending following the conclusion of the Cold War. This led to an industry shift from reliance on defense sales to one dependent upon commercial markets. Increasing foreign competition in the commercial aerospace market has led to contractions in the industry, resulting in mergers and acquisitions. Job losses from this consolidation have been compounded by the cyclical nature of the industry.

Due to these uncertainties, most of the workers who have lost their jobs are unlikely to return to the industry. These losses, coupled with pending retirements, represent a devastating loss of skill, experience, and intellectual capital to the industry.

REVERSE THE DECLINE AND PROMOTE THE GROWTH OF TODAY’S AEROSPACE WORKFORCE. The Commission was unable to agree to any immediate solutions to help stem the loss of jobs within the industry. It hopes that its recommendations for a high-level federal management structure focused on establishing a national aerospace consensus (Chapter 5) and other actions to promote the industry will have a positive effect in the future. What is clear is that industry, government, and labor must begin to work now to restore an aerospace industry that will be healthy, stable, and vibrant.

U.S. policy towards domestic aerospace employment must reaffirm the goal of stabilizing and increasing the number of good and decent jobs in the industry. The Administration and the Congress should consider the impact of domestic and international policies on U.S. aerospace employment.

ADDRESS THE FAILURE OF THE MATH, SCIENCE, AND TECHNOLOGY EDUCATION. The aerospace industry must have access to a scientifically and technologically trained workforce. In the long term, the Commission stresses that action must be taken to improve mathematics and science instruction across the entire education range—K-12 through graduate school. These actions and investments should include scholarships and internship programs to encourage more U.S. students to study and work in mathematics, science, and engineering fields. In addition, investments should be made in vocational education to develop a highly skilled workforce, including registered apprenticeship programs for skilled and technical occupations. Further, as recommended in Commission Interim Report #3, targeted tax credits should be made available to employers who invest in the skills and training programs needed by the industry.

In addition, the Commission concludes that emphasis must be placed on the concepts of “lifelong learning” and “individualized instruction” as key elements of education reform. It is likely that individuals now entering the workforce will hold five or more jobs in their lifetime and the education system must be prepared to deliver training and education to meet these changing skill requirements and meet labor market needs. U.S. community colleges are adept at designing and delivering workforce training and individualized instruction.

Our policymakers need to acknowledge that the nation’s apathy toward developing a scientifically and technologically trained workforce is the equivalent of intellectual and industrial disarmament and is a direct threat to our nation’s capability to continue as a world leader.

Recommendation #8

The Commission recommends the nation immediately reverse the decline in, and promote the growth of, a scientifically and technologically trained U.S. aerospace workforce. In addition, the nation must address the failure of the math, science and technology education of Americans. The breakdown of America’s intellectual and industrial capacity is a threat to national security and our capability to continue as a world leader. The Administration and Congress must therefore:

- Create an interagency task force that develops a national strategy on the aerospace workforce to attract public attention to the importance and opportunities within the aerospace industry;
- Establish lifelong learning and individualized instruction as key elements of educational reform; and
- Make long-term investments in education and training with major emphasis in math and science so that the aerospace industry has access to a scientifically and technologically trained workforce.

Chapter 9—Research: Enable Breakthrough Aerospace Capabilities

Conclusions

The United States must maintain its preeminence in aerospace research and innovation to be the global aerospace leader in the 21st century. This can only be achieved through proactive government policies and sustained public investments in long-term research and RDT&E infrastructure that will result in new breakthrough aerospace capabilities.

Over the last several decades, the U.S. aerospace sector has been living off the research investments made primarily for defense during the Cold War—intercontinental ballistic missiles, the Saturn V, space-based reconnaissance, the global positioning system, stealth and unmanned aerial vehicles. The challenges posed by our rapidly changing world—asymmetric threats, international competition, environmental

awareness, advances in technology—demand that we, like the Wright brothers 100 years ago, look at the challenges as opportunities for aerospace and turn them into reality.

Government policies and investments in long-term research have not kept pace with the changing world. Our nation does not have bold national aerospace technology goals to focus and sustain federal research and related infrastructure investments. It lacks a streamlined innovation process to transform those investments rapidly into new aerospace products, processes and services.

The United States has unlimited opportunities to revolutionize aerospace in the 21st century, opening up new markets and launching a new era of U.S. global aerospace leadership. The nation needs to capitalize on these opportunities, and the federal government needs to lead the effort. Specifically, it needs to invest in long-term enabling research and related RDT&E infrastructure, establish national aerospace technology demonstration goals, and create an environment that fosters innovation and provide the incentives necessary to encourage risk taking and rapid introduction of new products and services.

INCREASE PUBLIC FUNDING FOR LONG-TERM RESEARCH AND RDT&E INFRASTRUCTURE. The Administration and Congress should sustain significant and stable funding in order to achieve national technology demonstration goals, especially in the area of long-term research and related RDT&E infrastructure. Research areas that provide the potential for breakthroughs in aerospace capabilities include:

- Information Technology;
- Propulsion and Power;
- Noise and Emissions;
- Breakthrough Energy Sources;
- Human Factors; and
- Nanotechnology.

ESTABLISH NATIONAL TECHNOLOGY DEMONSTRATION GOALS. The Administration and Congress should adopt the following aerospace technology demonstration goals for 2010 as a national priority. These goals, if achieved, could revolutionize aerospace in the next half century much like the development of the jet, radar, space launch, and satellites did over the last half-century.

Air Transportation

- Demonstrate an automated and integrated air transportation capability that would triple capacity by 2025;
- Reduce aviation noise and emissions by 90 percent;
- Reduce aviation fatal accident rate by 90 percent; and
- Reduce transit time between any two points on earth by 50 percent.

Space

- Reduce cost and time to access space by 50 percent;
- Reduce transit time between two points in space by 50 percent; and
- Demonstrate the capability to continuously monitor and surveil the earth, its atmosphere and space for a wide range of military, intelligence, civil and commercial applications.

Time to Market and Product Cycle Time

- Reduce the transition time from technology demonstration to operational capability from years and decades to weeks and months.

ACCELERATE THE TRANSITION OF GOVERNMENT RESEARCH TO THE AEROSPACE SECTOR. The U.S. aerospace industry must take the leadership role in transitioning research into products and services for the nation and the world. Government must assist by providing them with insight into its long-term research programs. The industry must aggressively develop business strategies that can incorporate this research into new products and services. Industry

also needs to provide input to government on its research priorities. Together industry and government need to create an environment that will accelerate the transition of research into application. The Departments of Defense, Transportation, Commerce and Energy, NASA, and others need to work with industry and academia to create new partnerships and transform the way they do business.

Recommendation #9

The Commission recommends that the federal government significantly increase its investment in basic aerospace research, which enhances U.S. national security, enables breakthrough capabilities, and fosters an efficient, secure and safe aerospace transportation system. The U.S. aerospace industry should take a leading role in applying research to product development.

Promise for the Future

The aerospace industry has always been a reflection of the spirit of America. It has been, and continues to be, a sector of pioneers drawn to the challenge of new frontiers in science, air, space, and engineering. For this nation to maintain its present proud heritage and leadership in the global arena, we must remain dedicated to a strong and prosperous aerospace industry. A healthy and vigorous aerospace industry also holds a promise for the future, by kindling a passion within our youth that beckons them to reach for the stars and thereby assure our nation's destiny.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

National Academy of Sciences
National Academy of Engineering
Institute of Medicine
National Research Council

Aeronautics and Space Engineering Board / Transportation Research Board
Committee on Aerospace Research and Technology for Vision 2050

August 14, 2002

The Honorable John H. Marburger, III
Director
Office of Science and Technology Policy
Executive Office of the President
Washington, DC 20502
Subj: Aeronautics Research and Technology for 2050: Assessing Visions and Goals

Dear Dr. Marburger:

At the request of the National Aeronautics and Space Administration and the Federal Aviation Administration, the National Research Council recently established the Committee on Aeronautics Research and Technology for Vision 2050. The membership of the committee includes a cross section of senior executives, engineers, researchers, and other aviation professionals. The purpose of the committee is to assess the long-term visions and goals for U.S. civil aviation, as described in five key documents produced by the federal government. The committee's initial assessment, which is summarized in this letter, is based on its collective wisdom as well as inputs from other experts who participated in this phase of the committee's work. The attachments provide additional supporting information: a comparative assessment of the vision and goals documents examined by the committee, the committee's statement of task, and a list of committee members and other study participants. The work of the committee is ongoing, and late next year it will issue a much more detailed assessment of long-term technology goals.

Current U.S. visions for civil aviation correctly point out the importance of civil aviation. For example, NASA's recent Aeronautics Blueprint notes that the United States and the world are becoming "more dependent on the ability to move goods and people faster and more efficiently by air Over the last century, aviation has evolved to become an integral part of our economy, a cornerstone of our national defense, and an essential component of our way of life. Aviation generates more than \$1 trillion of economic activity in the United States every year, . . . Americans per capita use aviation more than any other country in the world, . . . [and] personal travel accounts for more than 50 percent of commercial air transportation."

To sustain our ability to reap the benefits that aviation provides, the U.S. visions consistently identify three main thrusts that long-term aeronautics research should address: safety and security, capacity of the air transportation system, and environmental compatibility (noise and emissions). The committee concluded, however, that U.S. visions and goals consistently overlook several key items: a description of the overall process, a clear set of guiding principles, and a strategy for overcoming transitional issues.

The process of organizing a long-term research and technology program for civil aviation should start with a systematic statement of the underlying problems and a unified national vision to ensure that efforts by individual departments and agencies of the federal government respond to these problems in a synergistic fashion. Currently, however, most of the five vision documents examined by the committee have not been endorsed by the heads of the agencies who chartered them, and they

contain goals that are inconsistent with the research and acquisition budgets of the responsible federal agencies. The situation raises questions about the relevancy of existing visions and demonstrates the need for federal agencies involved in civil aeronautics research and technology to support *and implement* a unified national vision.

The committee believes that the most critical long-term issue facing all aspects of the air transportation system is growth in demand for air travel. Safety, security, capacity, and environmental compatibility issues are all exacerbated by greater demand, and the effectiveness of near-term solutions in each of these areas will be diminished as demand for air travel in the United States doubles and triples in the decades ahead.

New technologies and the resulting operational concepts should be assessed in terms of their ability to solve the key problems that the air transportation system of the future must overcome. For example, in the next 50 years it will probably become technologically feasible to replace pilots and air traffic controllers with automated systems. But to what extent would such systems solve the key problems of today, and what new problems might they introduce? The guiding principle here should be to design synergistic partnerships between humans and automation that result in better performance than either could achieve alone, rather than simply replacing humans with computers.

Long-term goals and visions should support the development of technological solutions using a top-down approach that views the air transportation system as one element of a multimodal national transportation system. The desired future state of the air transportation system should be defined using a comprehensive architecture that combines process elements for each component (operational, system, technical, and economic) of the transportation system. The future vision should also consider transitional issues, such as the need for (1) an environment that is conducive to the introduction of new technologies (in terms of regulations, regulatory approval processes, the certification process, operational procedures, and the perceptions of system operators, the traveling public, and society at large), (2) interim improvements to the air transportation system along the way to the future, and (3) incentives that motivate government agencies and private industry to cooperate in defining and achieving a common vision. Achieving the vision may also be facilitated by designating an organization to serve as the federal advocate for air transportation now that the Federal Aviation Administration no longer has the legislative charge to promote aviation. Visions should also be recognized as dynamic, changing over time as societal needs and priorities change and as advances in technology alter our perception of what is possible.

In assessing the U.S. goals and visions, the committee also examined a comparable vision of civil aeronautics in Europe. The European vision highlighted two key areas that are missing from the U.S. visions. The latter do not include the satisfaction of consumer needs, in terms of the quality and affordability of air transportation, as a goal, perhaps because consumers do not seem to have been consulted when the U.S. visions were formulated. Also, although the U.S. visions as a whole recognize that national well-being depends on a national transportation system with a strong aviation element, they do not include primacy of the U.S. aeronautics industry as a goal. Competitiveness is so central to the European vision, however, that it appears in the title of the document that defines this vision: *European Aeronautics: A Vision for 2020—Meeting Society's Needs and Winning Global Leadership*.

Developing a comprehensive, unified vision for the future of the U.S. air transportation system—and generating widespread support to achieve the vision—will be a tremendous challenge. Fortunately, sometimes the flow of history leads to a confluence of events that creates an opportunity to meet great challenges. The 100th anniversary of powered flight, which will take place in 2003, may be an opportunity both to create a bold new vision for air transportation and to initiate vigorous action by government agencies and private organizations to pursue that vision. However, even with this opportunity, little is likely to happen without air transportation being clearly established as a

national priority with strong, focused leadership. In fact, the committee believes that providing such leadership is more important to the future of the air transportation system than any new technology.

Sincerely,

Ronald R. Fogleman
Chairman

cc: Fenton Carey, Commission on the Future of the U.S. Aerospace Industry
Charles Huettnner, Commission on the Future of the U.S. Aerospace Industry
Robert Pearce, National Aeronautics and Space Administration
Carl McCullough, Office of Science and Technology Policy
Herm Rediess, Federal Aviation Administration
Andres Zellweger, National Aeronautics and Space Administration

FOR *Greener Skies*
Reducing Environmental Impacts of Aviation

Committee on Aeronautics Research and Technology for Environmental Compatibility

Aeronautics and Space Engineering Board
Division on Engineering and Physical Sciences
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C.

Executive Summary

Providing rapid and safe transportation across the nation and around the world, contemporary aviation contributes significantly to the national economic vitality and to the business and pleasure of millions of citizens. In addition, the manufacture of aviation products provides substantial direct economic benefits as a source of jobs in the United States, and as the largest positive contributor to the balance of trade in goods. But large amounts of energy are required to propel modern jet transports, and thus both noise and emission of combustion products are a consequence of powered flight.

Scientific and technological progress in the 50 years since the advent of turbine engines has produced dramatic reductions in their noise and emissions. But even though individual airplanes are quieter and cleaner, the rapidly increasing demand for aviation services has mandated more airplanes and more flights, and so the total environmental consequences have increased and become more obvious. At the same time, the awareness of environmental issues and the political pressures to resolve them have also increased dramatically. Aircraft operations and the construction of new facilities are now seriously constrained by environmental restrictions. Indeed, the U.S. air transportation system is caught today between two powerful but conflicting expectations—the first for more services, the second for decreased environmental impact. The presumably short-term reduction in demand for air travel in the aftermath of the September 2001 attacks on the World Trade Center and the Pentagon does not resolve the issues addressed by this report. It merely provides an opportunity for advanced technology to mitigate existing environmental impacts before the inevitable resumption of demand growth makes them worse.

The technical challenges are too large and regulatory and economic incentives too small for industry acting alone to eliminate the environmental effects of the growth in air travel and the demand for aviation services. The federal government has long accepted part of the responsibility for the ad-

vance of aviation and for reducing its environmental impact. But today the federal research efforts are not commensurate with the intensifying severity of the problem. While the goals of the federal research program are admirable and focused on the right issues, the schedule for achieving the goals is unrealistic in view of shrinking research budgets and increasing isolation from industry and academia. As research budgets are cut, a higher percentage of the remaining funds are spent to support in-house work at National Aeronautics and Space Administration (NASA) research centers. This causes an even larger reduction in the percentage of research funding left for research and technology development by universities and industry.

Most of the federal funding available for addressing issues associated with aircraft noise and emissions is used for noise abatement at selected airports, primarily by sound-proofing buildings in high-noise areas outside airport boundaries or purchasing land to extend airport boundaries to encompass high-noise areas. Relatively little is spent on research and technology to control noise or emissions at the source. This funding scheme is a consequence of the way funds are raised and appropriated. Most of the funds appropriated for these purposes are raised from taxes on airline tickets, primarily for the purpose of subsidizing airport improvements or noise abatement measures in homes and other buildings near airports, and they are administered by the Federal Aviation Administration (FAA). Primary responsibilities for developing advanced aircraft technologies for reducing noise at the source, however, are assigned to NASA, which has no independent sources of funding to support aeronautics research.

Finding—Vigorous Action Required. Environmental concerns will increasingly limit the growth of air transportation in the 21st century unless vigorous action is taken to augment current research and technology related to the environmental impacts of aviation.

AIRCRAFT NOISE

Aviation noise reduces property values, contributes to delays in expanding airport facilities, and prompts operational restrictions on existing runways that increase congestion, leading to travel delays, high ticket prices, and high airline capital and operating costs. The situation would be much worse, however, if not for past investments in advanced technology. Over the past 30 years, the number of people in the United States affected by noise (i.e., the number of people who experience a day-night average sound level of 55 dB) has been reduced by a factor of 15, and the number of people affected by noise has been reduced by a factor of 100, as measured per unit of service provided (revenue-passenger-kilometer).

The most significant limitations to further reductions in the effect of aviation noise (or emissions) include growth in demand, long lead times for technology development and adoption, long lifetimes of aircraft in the fleet, high development and capital costs in aerospace, high residual value of the existing fleet, and low levels of research and development funding. While spending huge sums on local palliatives such as soundproofing buildings, the federal government reduced funding for the research that would quiet the entire fleet in the decades ahead. For example, the noise reduction element of NASA's Advanced Subsonic Technology Program was an excellent model for government-industry collaborations involved in commercialization of advanced technology. This program has been terminated, however, and replaced with a new program with fewer resources and less industry involvement.

In 2001, the FAA expended about \$500 million on noise abatement, while the FAA and NASA together expended less than \$60 million on noise and emissions research. The need to place more emphasis on research was noted in the fiscal year 2002 appropriations for the Department of Transportation, which directed that \$20 million from the Airport and Airway Trust Fund be used to accelerate the introduction of quieter aircraft technologies. These funds were provided to the FAA, with the expectation that it would "work directly with" NASA "to advance aircraft engine noise research," and about \$14 million is being used to augment NASA research funding in this area. Congress took this action because community opposition to aircraft noise is preventing the necessary expansion of some airports and because "aircraft noise results in millions of federal dollars being spent each year on mitigation measures, diverting funds which could be applied to capacity enhancement or safety projects" (Congress, 2001). The committee endorses this action as a first step in reducing the imbalance in the allocation of aircraft noise funding. Much more needs to be done.

Most federal research on noise reduction is performed or managed by NASA. NASA's goals for noise reduction are to cut the perceived noise of future subsonic aircraft in half

(i.e., by 10 dB) between 1997 and 2007 and to cut the noise in half again by 2022 (NASA, 2002). Achieving these goals will be very difficult—and will require a rate of technological advance that is greater than the historical record would predict (see Figure ES-1). Furthermore, even in the unlikely event that these aggressive goals are achieved, noise may continue to constrain the U.S. air transportation system, in large part because communities near airports are placing greater emphasis on a low-noise environment as part of their quality of life.

The Federal Interagency Committee for Aircraft Noise facilitates information sharing among federal agencies interested in aircraft noise. This committee could be strengthened and made more effective if agencies appointed personnel who have budgetary authority within their home organizations as members of the committee.

Recommendation—Balanced Allocation of Funds. Federal expenditures to reduce noise should be reallocated to shift some funds from local abatement, which provides near-term relief for affected communities, to research and technology that will ultimately reduce the total noise produced by aviation. Currently, much more funding is devoted to local abatement than to research and technology. Also, to avoid raising unrealistic expectations, the federal government should realign research goals with funding allocations either by relaxing the goals or, preferably, by reallocating some noise abatement funds to research and technology.

Recommendation—Technology Maturity and Scope. NASA and other agencies should sustain the most attractive noise reduction research to a technology readiness level high enough (i.e., technology readiness level 6, as defined by NASA) to reduce the technical risk and make it worthwhile for industry to complete development and deploy new technologies in commercial products, even if this occurs at the expense of stopping other research at lower technology readiness levels. NASA and the FAA, in collaboration with other stakeholders (e.g., manufacturers, airlines, airport authorities, local governments, and nongovernmental organizations), should also support research to accomplish the following:

- Establish more clearly the connection between noise and capacity constraints.
- Develop clear metrics for assessing the effectiveness of NASA and FAA noise-modeling efforts.
- Implement a strategic plan for improving noise models based upon the metrics.
- Harmonize U.S. noise reduction research with similar European research.

Recommendation—Interagency Coordination. Interagency coordination on aircraft noise research should be enhanced by ensuring that the members of the Federal Interagency Committee for Aircraft Noise have budget authority

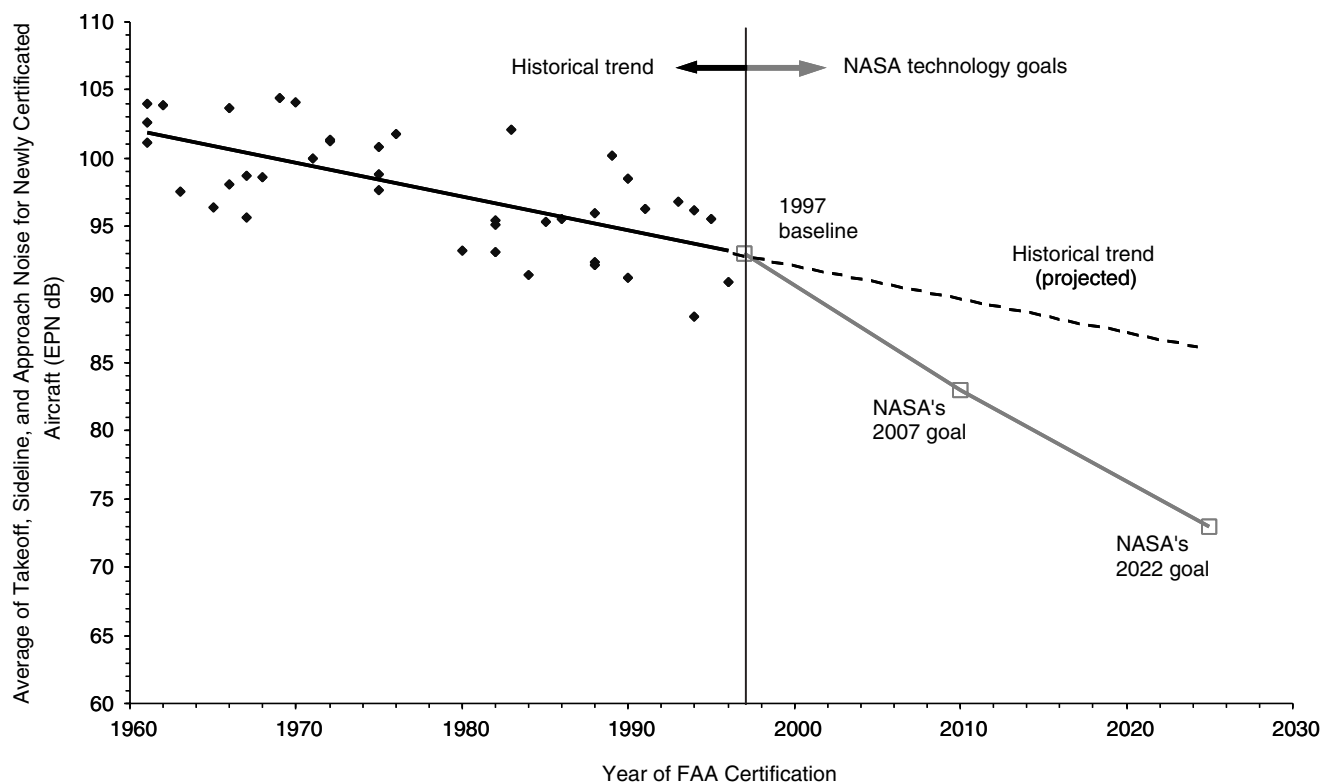


FIGURE ES-1 Historical trends in aircraft noise compared with NASA's noise goals. SOURCE: Lukachko and Waitz, 2001.

within their own organizations to implement a coordinated strategy for reducing aviation noise.

ENGINE EMISSIONS

The aviation industry is growing, and the use of aviation fuel is increasing at a rate comparable to that for other uses of fossil fuels. Between 1992 and 1999, the United States increased its consumption of natural gas (10 percent), petroleum (12 percent), and coal (13 percent). The consumption of jet petroleum increased by 14 percent, and the consumption of petroleum products by the entire transportation industry increased by 15 percent. Jet petroleum represents 3 percent of the total U.S. energy consumption and some 10 percent of petroleum consumption.

All other factors being equal, the amount of emissions produced by aircraft is essentially proportional to fuel consumption, which is proportional to flight activity. One option for reducing emissions is advanced technology, and during the past 50 years major advances in aircraft turbine engines have been realized as a result of extensive efforts by engine manufacturers and cognizant government agencies. In the United States, NASA has been a significant contributor to these sustained advances. From the outset, the goals of these efforts have included improved engine reliability, durability, and fuel efficiency, all of which have significant economic implications for the airlines. Dramatic progress has

been made in all three of these crucial aspects, but the increased efficiencies of individual airplanes are not sufficient to decrease the total emissions of a global fleet growing in response to accelerating demand. For newly designed aircraft, advanced technology could reduce fuel consumption per revenue-passenger-kilometer by about 1 percent per year for the next 15 to 20 years. During the same time, however, the demand for global air transportation services is expected to increase by 3 to 5 percent per year (see Figure ES-2).¹ An aggressive, broad-based research program that includes technology to improve propulsion systems, the airframe, and operational systems and procedures could significantly close this gap, but existing allocations of research funds within NASA and the FAA are insufficient to support such a program.

Funding allocated to achieve NASA's goals for reducing carbon dioxide (CO₂) and oxides of nitrogen (NO_x) is insufficient to reach the specified milestones on time. Research to reduce NO_x and improve engine efficiency, although part of the NASA Ultra Efficient Engine Technology Program, has been significantly reduced in scope in the past few years to

¹The September 11, 2001, attacks on New York City and Washington, D.C., will shift plots of future growth in air travel to later years. However, lacking data on how much of an adjustment to make, the committee is relying on historical projections which reflect trends that are expected to resume in the long term.

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and operators to reduce environmental impacts should all be considered.

Manufacturers attempt to produce new aircraft that cost less and are more reliable than their predecessors. At the same time, government intervention is important to encourage manufacturers, operators, and consumers of aviation services to reduce the environmental consequences of aircraft operations, which will sometimes increase costs. There are international implications, too, because many domestic rules are written in accordance with multinational agreements established by the International Civil Aviation Organization; also, other nations sometimes unilaterally establish rules that affect the operations and competitiveness of U.S. aircraft or airlines.

Thus, the government is an active participant in promoting aviation and in ensuring the environmental compatibility of aviation, both by assisting in the development of new technologies and in regulating the noise and emissions that attend aircraft operations. An important question is whether the current policy framework is well equipped to satisfy both environmental goals and the public's demand for aviation services. One way to consider this question is to examine the full costs for consumers, operators, and manufacturers of doing business in competitive markets, including the costs related to environmental compatibility and the consequences of inadequate facilities and capacity. Knowing the full costs of operations, the likely costs and consequences of technological intervention, and the costs of the potential solutions (technological and regulatory) would allow policy alternatives to be ranked and better policy decisions to be made.

An associated policy issue is whether it is possible to create marketplace incentives for industry to develop and deploy environmental technologies that go beyond regulatory requirements. For example, a few major European airports have implemented landing fees that reward operators who use ultralow- NO_x combustors while penalizing operators using standard combustors. The cost differential does not appear to be a sufficient financial incentive to most international air carriers, for whom operations at these airports represent a very small fraction of their total operations. As a result, advanced combustors, some of which can reduce NO_x as much as 60 percent below international standards, have a limited market because (1) they cost more than simpler combustors (that reduce NO_x to about 35 percent below current standards) and (2) they provide no economic benefits to offset their higher cost.

Recommendation—Considering All Costs and Benefits. To support the formulation of environmental goals and air transportation policies, government and industry should invest in comprehensive interdisciplinary studies that quantify the marginal costs of environmental protection policies, the full economic benefits of providing transportation services while reducing the costs (in terms of noise, emissions, and congestion), and the potential of financial incentives to en-

courage the development and use of equipment that goes beyond regulatory standards.

A CALL FOR VIGOROUS FEDERAL LEADERSHIP

Strong action is essential to avert a paralyzing collision between the growth of aviation and increasing concerns about the quality of the environment. A national strategy and a federal plan for action are much needed. Two significant issues must be faced:

1. *Technology lead times.* With service lives of 25 to 40 years for individual models of commercial aircraft, it can take decades for a major technological improvement to appear in a majority of the commercial fleet. NASA, the FAA, and industry could reduce lead times by collaborating in the development of mature, proven technology that the FAA is willing to certify, airlines are willing to purchase, and manufacturers are willing to develop.
2. *Economic incentives.* The government and the public must recognize the need for economic incentives for manufacturers and airlines to embrace technologies that minimize environmental impacts. Although passengers are unlikely to pay more to ride on an airplane with lower takeoff or approach noise, they may be willing to pay more to fly in a newer airplane that offers other advantages in addition to reduced environmental impacts. More certain, however, is the ability of the government to establish economic incentives for using advanced environmental technologies. Possibilities include tax advantages for operators of “greener” airplanes and direct grants for environmental innovation or leadership.

Finding—Status of Environmental Research. Research seeking to mitigate the environmental impacts of aviation is important to national and global well-being, but present efforts are operating with ambitious goals, unrealistic timetables for meeting them, and few and diminishing resources.

The ultimate goals for environmental research related to aviation remain uncertain for several reasons:

- The actual effects of aviation on the environment are uncertain.
- Aircraft emissions are only a small contributor to global atmospheric issues.
- Solutions may involve revolutionary changes in aircraft design.
- The noise levels that will ultimately prove acceptable to the general public (especially to people living near airports) and eliminate noise as a critical limitation on the growth of air traffic are unknown.

Recommendation—Additional Research. To reduce conflicts between the growth of aviation and environmental stewardship, NASA, the FAA, and the Environmental Protection Agency (EPA) should augment existing research by developing specific programs aimed at the following topics:

- determining which substances identified by the EPA as hazardous air pollutants are contained in aircraft emissions and need to be further reduced
- understanding and predicting atmospheric response to aircraft emissions as a function of time on local, regional, and global spatial scales
- exploring the suitability of alternate sources of energy for application to aviation, taking full account of safety and operational constraints

Recommendation—Taking Advantage of Experience. The following lessons, learned since the advent of jet-powered aircraft, should be used to formulate and evaluate strategies for reducing the environmental effects of aviation:

- Success is not easy—it requires government support and federal leadership in research and development of new technology. Establishing a strong partnership involving federal, state, industry, and university programs is essential to progress.
- Changes in the impact of aviation on the environment occur on the scale of decades as fleets evolve; technological success in reducing adverse impacts occurs on the same or longer scales.
- The formulation of technological strategies to reduce the environmental impacts of aviation is hampered by significant uncertainties about (1) long-term effects of aviation on the atmosphere, (2) economic factors associated with aircraft noise and emissions, and (3) the level of noise and emissions that ultimately will prove to be acceptable to airport communities and the general public, nationally and internationally.

With a final recommendation, the Committee on Aeronautics Research and Technology for Environmental Compatibility calls for leadership by the federal government to ensure the growth of an environmentally compatible national aviation capability in the 21st century:

Recommendation—The Federal Responsibility. The U.S. government should carry out its responsibilities for mitigating the environmental effects of aircraft noise and emissions with a balanced approach that includes interagency cooperation and investing in research and technology development in close collaboration with the private sector and university researchers. Success requires commitment and leadership at the highest level as well as a national strategy and plan that does the following:

- coordinates agency research and technology goals, budgets, and expenditures with national environmental goals and international standards endorsed by the federal government
- periodically reassesses environmental goals and related research programs to ensure that they reflect current understandings of the impact of specific aircraft emissions on the environment and human health
- takes advantage of the unique expertise of both government and industry personnel and reverses the current trend of lessening industry involvement in NASA-sponsored environmental research and technology development
- reallocates funds in accordance with long-term goals, shifting some resources from short-term mitigation in localized areas to the development of engine, airframe, and operational/air traffic control technologies that will lead to aircraft that are quieter, operate more efficiently, and produce fewer harmful emissions per revenue-passenger-kilometer
- supports international assessments of the effects of aircraft emissions and the costs and benefits of various alternatives for limiting emissions
- expedites deployment of new technologies by maturing them to a high technology readiness level (i.e., technology readiness level 6, as defined by NASA) and providing incentives for manufacturers to include them in commercial products and for users to purchase those products

Aviation is critically important to individuals, the economy, and the nation, yet the U.S. aviation industry has struggled with serious capacity issues, conflicting expectations regarding delays and environmental impacts, and long-standing federal policies on the expenditure of funds that limit support for the very research that is the key to long-term success. Vigorous federal leadership is essential to overcome funding restrictions and political issues and ensure that research and technology development proceeds as rapidly as is scientifically possible.

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Persistent and Critical Issues in the Nation's Aviation and Aeronautics Enterprise

Released by
Aerospace Division, ASME
Washington, DC

November 2003

ASME is a 120,000-member professional organization focused on technical, educational and research issues of the engineering and technology community. ASME conducts one of the world's largest technical publishing operations, holds numerous technical conferences worldwide, and offers hundreds of professional development courses each year. ASME sets internationally recognized industrial and manufacturing codes and standards that enhance public welfare and safety. This statement represents the views of the ASME Aerospace Division, Environment and Transportation Group, Council on Engineering, and is not necessarily a position of ASME as a whole.

EXECUTIVE SUMMARY

FINDINGS

- The support provided by the federal government to civil aeronautics research and development (R&D) is not commensurate with the importance of air transportation in the nation's economy and security, as well as in the global economy and the international war on terrorism. The Committee believes that a vigorous national advanced aeronautical R&D program with strong leadership by the federal government is essential to the United States: (1) maintaining a strong national transportation system in support of a world class economy; (2) sustaining and enhancing its leadership position in global air transportation; and (3) maintaining homeland security and winning the war on terrorism.
- The Committee believes that the U.S. share of the world aviation market can be increased with advanced technology. In addition, with strong cooperation among commercial interests, universities, and government, U.S. standing in aeronautics will once again flourish. Failure to pursue such initiatives, however, will lead to further erosion in market share and a loss of global leadership for the United States in the aeronautics marketplace.
- There are opportunities for new industrial companies and employment opportunities to emerge based upon technological advances made possible by a vigorously funded aerospace R&D program at the national level. Exciting new opportunities continue to exist for major advances in many areas of aeronautical technology, including automated flight vehicles, "fail-safe" avionics, new platforms/configurations, efficient propulsion, "quiet" aircraft, enhanced safety, and "zero" emissions aircraft.
- Historically, The National Aeronautics and Space Administration ((NASA) has had a pre-eminent combination of talent and experience in aeronautics research with a network of test facilities and research aircraft unmatched elsewhere in the world. However, through a combination of internal and external factors, that capability has substantially declined to the point that the nation's leadership in aeronautics is at serious risk.
- Among existing federal agencies, only NASA has the mandate to provide leadership in civilian aeronautics basic research and to pursue partnerships with the nation's universities and industry. In order to safely and economically incorporate new concepts and technologies into commercial and military aircraft it is essential to keep these partnerships vigorous and healthy.
- As noted in various reports, (see Appendix I) it is apparent that one U.S. civil aircraft company is in competition for its existence with a consortium of companies from Germany, France, Great Britain, and Spain, supported and subsidized by these governments. Efforts to perform generic, advanced research in support of civil aircraft by the U.S. government through NASA are often criticized as being a form of "corporate welfare." This concern is unfounded. The complexity of aeronautical systems, the industrial base needed to design and build them, and the vast network of companies involved make an investment in aeronautics a matter of national welfare and strategic importance. Competition among manufacturers of domestic aircraft components can only increase quality and advance technology development. A major goal of U.S. government research should be to provide the basis for new private companies to enter the aircraft manufacturing market and to ensure overall global leadership for U.S. industry in aeronautics.

- The Europeans and Canadians have recognized the essential role that federally funded basic research plays in support of the private sector. For many years this has been true of the U.S. as well, but in recent years that commitment has weakened significantly. It is past time for its renewal if the U.S. is to remain a leader in civilian aeronautics and pre-eminent in military aeronautics.

Based on the findings of this statement and earlier studies (see Appendix I), the Steering Committee makes the following recommendations, in priority order:

POLICY RECOMMENDATIONS

- The United States should commit to (a) maintaining dominance in military aviation systems and aeronautical technology and (b) re-establishing leadership in commercial aviation and air transportation systems.
- The Federal Aviation Administration (FAA) and NASA in a synergistic partnership with the DoD should be given the mandate to create anew a world-class national aeronautics research program. In this regard the recent cooperation among the Departments of Transportation, Homeland Security, Commerce, and Defense, along with the FAA and NASA to create the Next Generation Air Transportation System is to be applauded and encouraged. It is too soon to know the outcome of this initiative, but the establishment of a Joint Planning Office (JPO) is a positive first step toward greater interagency interaction and productivity. This initiative needs to be closely watched to assess its effectiveness, and appropriate steps taken to ensure its success or to seek alternative means, if necessary.
- The Committee believes that the aeronautics portion of the NASA budget should be increased to \$2.1 billion (which includes full cost pricing) over the next eight years, with a long-term target of attaining a level of 10 percent of the total NASA budget. Achieving this target would re-establish aeronautics funding, as a percentage of the NASA budget, at its pre-1990 level.
- Our Committee is very pleased that the Congress and the Administration has, in recent years, followed the recommendation of the Quadrennial Defense Review Report and the Defense Science Board that three percent of the total Department of Defense (DoD) budget be allocated toward defense science and technology (S&T) programs. However, we are concerned that even so, the "seed corn" funding for basic research continues to be shortchanged. Accordingly, our Committee recommends that the goal of DoD S&T programs comprising AT LEAST three percent of the total DoD budget be continued, but that funding for basic research (6.1) be increased to \$2.8 billion over the next five years.
- Federally funded programs specifically designed to attract and retain the best young people in the aeronautics community should be established and supported. NASA fellowships during the Apollo program years and United States Air Force (USAF) "Palace Knight" programs, for example, were effective, but need current counterparts.
- The Committee believes the U.S. should emphasize the development of the advanced aeronautical technologies required to maintain leadership in: 1) subsonic aircraft, 2) high-speed (supersonic) aircraft, and 3) short-haul aircraft (i.e., commuter aircraft, rotorcraft, and general aviation aircraft).

- Flight demonstrations (jointly funded by DoD and NASA) should be sustained at an annual budget level sufficient to determine the integrated performance of promising and dramatic new emerging technology opportunities.

TECHNOLOGY RECOMMENDATIONS

- Research into avionics systems and their applications should be aggressively pursued because their use is pervasive and is often critical to the success of advanced aircraft developments.
- Research and development into Uninhabited Air Vehicles (UAVs) should be given sustained support addressing issues of reliability, maintainability and cost, so that the full potential of these promising aircraft can be realized.
- Federal programs need to recognize that retaining national leadership in aircraft propulsion demands a program balanced between near term needs, driven by market forces, and longer-term investments required to achieve transformational national capabilities. Quieter, more environmentally friendly aircraft engines are not only possible, but highly desirable over the near- and longer-term. More distant, but intriguing, are the possibilities for engines using alternative fuels, including hydrogen. A vigorous pursuit of these technologies is likely to pay rich dividends to the United States air transportation system and the national economy.
- Fundamental advances in information technology should be vigorously pursued to address the increasing complexity of design decisions and the high costs incurred when inappropriate decisions are taken at early stages in system design based upon inadequate information and knowledge. Research on new and more effective prediction methodologies are sorely needed to meet this challenge. Computational Fluid Dynamics (CFD) methods, for example, have evolved to the point of achieving good correlation with test results, but are so computer-time intensive as to be currently impractical for the multiplicity of calculations needed for design of optimum configurations.
- Methodologies that facilitate the development of cost-effective, extraordinarily reliable software and systems for safety critical operations should receive the strongest possible support. Not only will such an investment help to revitalize the nation's aerospace activities, it will also enhance industrial competitiveness and national security and contribute to U.S. technology leadership well beyond aeronautics.
- Composite-Structures research is a critical enabling technology for advanced aeronautical development, and should be vigorously supported. In particular, new advances in manufacturing techniques for large-scale composite structures are required to promote the development of a new generation of aeronautical vehicles.
- Significant new aerodynamics research is required in support of innovative and promising applications ranging from micro UAVs, to Vertical Takeoff and Landing (VTOL) regional transports to Single Stage to Orbit (SSTO) launch vehicles and hypersonic missiles.
- Essential simulation, ground, and flight-testing capabilities must be preserved and new, more productive capabilities should be developed - including physical infrastructure and personnel - so that new generations of advanced aircraft can be designed safely to be competitive in the world market.

- There is a continuing need for R&D into flight mechanics and control for new, innovative configurations including un-piloted aircraft. Research to minimize if not entirely eliminate the impact of pilot and operator errors on flight safety should be a primary focus.

SECURING THE FUTURE OF U.S. AIR TRANSPORTATION

A System in Peril

Committee on Aeronautics Research and Technology for Vision 2050

Aeronautics and Space Engineering Board
Division on Engineering and Physical Sciences

Studies and Information Services
Transportation Research Board

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

Executive Summary

As recently as the summer of 2001, many travelers were dreading air transportation because of extensive delays associated with undercapacity of the system. That all changed on 9/11, and demand for air transportation has not yet returned to peak levels.¹ Most U.S. airlines continue to struggle for survival, and some have filed for bankruptcy. The situation makes it difficult to argue that strong action is urgently needed to avert a crisis of undercapacity in the air transportation system. Yet that remains the case. History shows that crises of confidence, economic downturns, and international conflicts can depress the demand for air transportation, but only over the short term. In every earlier case, the long-term trend of increasing demand has reasserted itself. Assuming that current events have fundamentally and permanently changed the public's demand for air transportation is not a sound approach to preparing for the long-term future of the air transportation system. Current events have provided an opportunity for U.S. national leadership to create a comprehensive, widely accepted long-term vision and a coherent set of requirements from all federal agencies with a major stake in the air transportation system. The continued absence of a national-level endeavor to address the current situation threatens to place the air transportation system in increasing peril.

To help assure the future of the U.S. commercial air transportation system, the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administra-

tion (FAA) requested that the National Research Council establish the Committee on Aeronautics Research and Technology for Vision 2050. The committee was charged with assessing (1) the visions and goals for U.S. civil aviation, as described in five key documents produced by the federal government,² and (2) technology goals for the year 2050. The committee issued a letter report on August 14, 2002, to address the first topic.³ Current U.S. visions for civil aviation correctly point out the importance of civil aviation. To sustain our ability to reap the benefits that aviation provides, the U.S. visions consistently identify three main areas that long-term aeronautics research should address:⁴

- capacity of the air transportation system (in terms of passenger-miles, cargo-ton-miles, and aircraft operations)
- environmental compatibility (noise and emissions)
- safety and security

The committee concluded, however, that U.S. visions and goals consistently overlook several key items:

- a clear set of guiding principles
- a description of the overall process for developing and achieving a widely endorsed long-term vision for the air transportation system

¹This report uses demand generally to refer to both consumer demand (the amount of air transportation services purchased, in terms of passenger-miles and cargo-ton-miles) and the load imposed on the air traffic control system (in terms of aircraft operations). Demand reflects the response of consumers to prices and the shape of the air transportation demand curve. Consumer demand is closely linked to demand on the air traffic control system, as individual airlines adjust routes, schedules, levels of service, prices, etc., to both stimulate and satisfy consumer demand.

²The complete statement of task appears in Appendix A, which also lists the visions assessed by the committee. A summary of the committee's comparative assessment appears in Appendix B.

³National Research Council (NRC). 2002. Aeronautics Research and Technology for 2050: Assessing Visions and Goals—Letter Report. Washington, D.C.: National Academy Press. Available online at <www.nap.edu/catalog/10518.html>.

⁴Items in this and other lists are either listed alphabetically or grouped topically. The committee did not prioritize research areas in each list.

- a strategy for overcoming transitional issues
- consumer satisfaction
- primacy of the U.S. aeronautics industry

Securing the future of the air transportation system requires that change within the system be accelerated quickly enough and directed with enough agility to avoid problems and achieve future goals while managing (1) the influence of increased demand and other external pressures and (2) conflicts between different goals and stakeholders. The process of achieving the long-term vision must be robust enough to prevent the system from changing too slowly, drifting, or going in the wrong direction.

The process of improving the long-term performance of the air transportation system—and organizing a corresponding long-term research and technology program—should start with a unified, widely endorsed national vision that specifies goals in each key area of interest to the commercial aviation community. The continued success of aviation and the benefits that it provides will require changes to accommodate increased demand. The committee found this to be the most critical long-term issue facing all aspects of the air transportation system. Issues associated with safety, security, and environmental compatibility are also exacerbated by greater demand, and the effectiveness of currently envisioned near-term solutions in each of these areas would be diminished if demand for air travel in the United States doubles over the next 10 to 35 years, as currently projected. Increasing passenger throughput enough to keep up with increased demand requires eliminating constraints and improving the flexibility of the system enough to overcome localized capacity problems while accommodating the full range of authorized users (commercial, private, and military). For example, eliminating the effects of adverse weather is not enough; in many areas, the baseline capacity of the system (in good weather) must also be greatly increased to accommodate a deregulated airline industry as it strives to meet user demands for convenient service. This requires research leading to improvements in every element of the air transportation system.

The future vision of the air transportation system should be supported by research and technology goals leading to improved performance in terms of en route comfort of passengers, the convenience of passenger travel and air freight service (including travel time), the cost of moving passengers and cargo (including the cost of developing and manufacturing new aircraft and aircraft systems), and the societal impact of aviation (in terms of the consumption of nonrenewable fuels, emissions, land use, noise, safety, security, reduced congestion in other modes of transportation, employment, and other effects on the national economy). Measurable long-term targets supported by sound analyses should be established to assess progress toward the goals. Research should support the establishment of quantifiable goals in areas where progress is difficult to measure.

The air transportation system is supported by a core of dedicated government and industry personnel who are developing new operational concepts, architectures, and modernization plans. Yet no single organization has the responsibility and authority for developing a comprehensive solution to the challenges faced by the U.S. air transportation system. Business as usual, in the form of continued, evolutionary improvements to existing technologies, aircraft, air traffic control systems, and operational concepts, is unlikely to meet the needs of air transportation over the next 25 to 50 years. The disparity between (1) the rate at which demand is increasing and (2) the rate at which technology is reducing aircraft noise and emissions is becoming increasingly difficult to overcome because technical advances are becoming increasingly difficult to achieve. Without strong, focused leadership, the likely result will be an air transportation system where growth in demand has been greatly curtailed by undercapacity; the environmental effects of aviation; customer dissatisfaction with available levels of comfort, convenience, and cost; and/or factors related to safety and security.

The committee believes that strong action by a federal agency or office to provide such leadership, with the broad support of the administration and the Congress, would do more to improve the ability of national aeronautical research and development programs to achieve their goals than any other change in the management or content of the programs themselves. The designated office should have (1) the responsibility, authority, and financial resources necessary for defining air transportation system architectures through a centralized planning function, (2) an understanding of the interactions among system performance parameters, demand, and economic factors, such as the methods used to fund federal activities in support of the air transportation system, and (3) the credibility and objectivity to garner the active support of other air transportation stakeholders in government, industry, and the general public. This will require, among other things, a leadership group composed of individuals with a broad aviation perspective and a willingness to accept the risks of looking ahead and allowing others to help define the future.⁵

PROCESS FOR CHANGE

The aviation system is unique in that it has one federal agency (NASA) responsible for long-range research and development and another agency (FAA) that supplies traffic management systems and services and regulates the carriers and manufacturers. The cultures, missions, and operating practices of NASA's aeronautics enterprise and the FAA are

⁵Assessing the organization and role of specific government agencies was beyond the scope of this study (see Appendix A), so no recommendation is made regarding which federal office or agency should be designated to provide the required leadership.

quite distinct, as would be expected when comparing a research organization with an operational organization. Nonetheless, they are the federal government's principal agents for operating and improving the technical capabilities of the air transportation system.

A national vision, clear technology goals, and strong, focused leadership are necessary to improve the competitiveness of the U.S. aeronautics industry and enable the air transportation system to satisfy increased demands for air travel without degrading system safety, security, environmental compatibility, or consumer satisfaction. Also required is a process for integrating, organizing, and directing aeronautics research and technology development and a clear understanding of organizational roles. Action necessary to achieve the above is encapsulated in the process for change that is defined in the following summary recommendation:

Recommendation. Process for Change. Establish air transportation as a national priority with strong, focused leadership. Air transportation system technology planning and development should be done in the context of a process driven by the needs of system users and the nation as a whole.

1. Implement a public/private process for change, as follows:
 - Designate a federal agency or office to provide strong leadership in overcoming the challenges faced by the U.S. air transportation system.
 - Establish an interagency process for developing and achieving a widely endorsed long-term vision of the air transportation system that includes a clear set of guiding principles and a strategy for overcoming transitional issues.
 - Document the process.
 - Coordinate action and resolve disputes among stakeholders in the aviation community with different concerns and priorities (e.g., manufacturers and operators; executives and employees; pilots, controllers, and passengers; local, federal, and state governments; regulators; the military; and general aviation).
 - Gather and analyze feedback on how well the process is working from the perspective of all interested parties, especially when conditions change, to identify problems before serious incidents or disruptions occur and to recognize new opportunities.
 - Formally review the process and process outputs at least every 4 years.
 - Update the process.
2. The output of the process should include the following:
 - A better understanding of future demand for air transportation to make sure that changing trends will be detected as soon as possible.
 - A unified, long-term national vision endorsed and supported by the aeronautics community as a whole and cognizant federal agencies.
 - Broad public policies to support the vision.
 - Long-term operational concepts to meet the vision and to serve as a continuing resource for guiding change and coordinating action by different parties.
 - System architectures to realize the operational concepts.
 - An understanding of how the U.S. air transportation system of the future will fit into the national (intermodal) transportation system and the international air transportation system.
 - Validated research and technology requirements.
 - An implementation plan to achieve all of the above, including a clear understanding of government and industry roles in developing precompetitive and noncompetitive aeronautical research and transitioning the results of civil and military government research to commercial development.
3. A comprehensive suite of system models should be developed, validated, and maintained to support informed decision making throughout the process. Models should encompass the following:
 - demand
 - economics
 - environmental effects
 - existing and new technologies
 - human performance
 - interactions with other modes of transportation
 - new operational concepts
 - organizational factors
 - security threats and preventive measures
 - system engineering
 - transition (from old to new technologies, systems, and organizational structures)
4. A commitment should be made to support a stable long-term research program to provide the knowledge, tools, and technologies needed throughout the process. At a low level, the research program should investigate innovative research ideas that challenge accepted precepts.

The following sections describe in more detail specific actions for improving the performance of (1) the air transportation system as a whole, (2) modeling and simulation capabilities necessary to support improvements in the air transportation system, and (3) individual aircraft.

IMPROVING THE AIR TRANSPORTATION SYSTEM

Developing meaningful and useful operational concepts stemming from a broadly defined vision of the air transportation system 25 to 50 years hence is a critically important task in the process of improving the performance of the system. To meet this challenge, the federal government, working with other stakeholders in the air transportation system, should develop a coherent set of operational concepts supporting a vision of the air transportation system in the 2050

time frame. These concepts should encompass a range of potential changes in technology, society, and the air transportation system itself. They should be used to guide long-term research and the evolution of and transition to a more advanced air traffic management system. The concepts should be continually, objectively, and rigorously evaluated (for example, through comprehensive simulation and modeling) and iterated to reflect feedback from stakeholders, conflicts between alternative concepts, and the best understanding of the future costs, benefits, and requirements that are likely to evolve in response to changes in the real world, the current state of technology and systems operations, and future expectations.

The research and technology requirements should be tailored to meet the requirements of future operational concepts. Enabling technologies applicable to a wide range of operational concepts should be developed in parallel with research to develop and evaluate long-term operational concepts so that the necessary technologies will be ready for whichever operational concept proves to be most beneficial. Technology areas of particular interest include the following:

- design of human-integrated systems
- distributed, collaborative decision making
- autonomous and interactive technologies
- noise and emissions locally, regionally, and globally
- wake vortices
- situational awareness
- systems-engineering methods
- avionics

Technological research alone is insufficient to achieve the future vision. Research is also needed to (1) better understand the economic, environmental, political, institutional, and managerial factors involved in achieving key goals, (2) take advantage of synergies among these factors, and (3) overcome related impediments. The federal government should support research to develop improved processes and methods in the following nontechnology areas:

- economics
- regulations, certification requirements, and operating procedures
- resolution of conflicting objectives of different stakeholders
- societal concerns about aircraft noise and emissions

MODELING AND SIMULATION

Federal, industrial, and academic institutions in the United States have tremendous research capabilities and resources. Achieving the future vision of the air transportation system requires that research be directed at technical capa-

bilities most likely to achieve long-term performance goals. Complementary use of field tests, laboratory tests, modeling, analysis, and simulation would improve the ability to (1) measure systemwide behavior of the air transportation system, (2) assess the performance of proposed operational concepts, technologies, and other changes, and (3) make informed investment decisions to reduce the schedule, cost, and technical risks of system improvements. In addition, the process of securing the future would be greatly facilitated if the federal agencies that support research in aviation system models would improve their coordination, especially with regard to the following:

- research plans
- participation of industry and academia
- criteria for maintenance and validation
- availability of models
- use of models by decision makers

The government and other interested parties should support additional simulation and modeling research in the following areas:

- interoperability
- safety analysis
- demand and demand allocation
- validation of models and suites of models
- formation of a suite of system models
- role of humans in the aviation system of the future

IMPROVING AIRCRAFT PERFORMANCE

Improvements in aircraft performance are critical to achieving necessary improvements in almost every aspect of the overall performance of the air transportation system. Innovative long-range research leading to the implementation of new operational concepts is also required for the air transportation system to take full advantage of gains in the performance of commercial aircraft.

To improve the performance of aircraft through 2025, federal agencies should continue to support research leading to evolutionary improvements in aircraft performance. Looking out to 2050, however, large gains in aircraft performance are unlikely to be achieved without innovative long-range research leading to new aircraft concepts and technologies. Areas of particular interest include the following:

- analytical tools
- composite materials
- environmental consequences of aircraft noise and emissions
- low emissions combustor technology
- nanotechnology
- nontraditional aircraft configurations

- nontraditional power and propulsion concepts
- passive and active control of laminar and turbulent flow
- high-temperature engine materials and advanced turbomachinery

Technologies specifically related to personal air vehicles, uninhabited air vehicles, supersonic aircraft, or runway-independent air vehicles have the potential to improve the performance of the air transportation system, especially in

niche areas. However, research in these areas will not be able to resolve the overall capacity problems that are the primary challenge to the continued success of the air transportation system over the long term. Accordingly, the committee did not examine technologies related to these vehicle classes and makes no recommendations concerning the future direction of research in these areas. Nonetheless, the process for change recommended by the committee would facilitate the planning of research for all vehicle types.



Aerospace Research & Development



A CASE FOR R&D:

U.S. Aviation and Space Leadership at Risk

America is in danger of losing its position as the global leader in aerospace.

Much has been done to develop a national vision for aerospace, including President Bush's moon/Mars initiative, solid defense funding in procurement and research and development (R&D), and the administration's roadmap to revamp the U.S. air traffic management system.

However, NASA and FAA research and development programs in key aeronautics sectors are insufficient, and there is little or no alignment across government agencies to encourage and facilitate joint benefits.

Our aerospace heritage began heroically in the pale sands of Kitty Hawk, and a century later renewed pride was stirred as rover vehicles landed in the red dust of Mars.

The United States cannot maintain its historic leadership in developing the innovative technological

capabilities that support domestic and international civil aviation, as well as inspire interplanetary space exploration, without significantly increasing civil sector R&D investment.

The European Union (EU) has moved aggressively

to assume global leadership in civil aviation and space by increasing its investment in its aerospace manufacturers. Elsewhere, Asia has targeted aerospace as a strategic industry, marked by a successful manned mission into space by China in late 2003.

Alarmed at the prospect of insufficient commitment and investment, the Aerospace Industries Association in 1999 laid out a five-year improvement plan that had some success.

Defense Department research, development, test, and evaluation (RDT&E) budgets were increased by \$69 billion, and funding for new concepts appears to be on a firm and focused track.

The annual NASA budget, however, has barely kept pace with inflation. Funding at the space agency for aeronautics, space shuttle safety upgrades, infra-

structure recapitalization, and other critical areas has declined significantly in recent years.

The situation is even worse at FAA where budgets for research, engineering, and development (RE&D) are the lowest they have been in 30 years and continue to decline.

As NASA and FAA aeronautics budgets decrease, the EU drive to gain leadership over the United States continues in such sectors as commercial aviation, rotorcraft, space launch, satellite manufacturing, modern wind tunnels, and satellite navigation systems.

Significant increases in funding are needed to remedy the U.S. position.

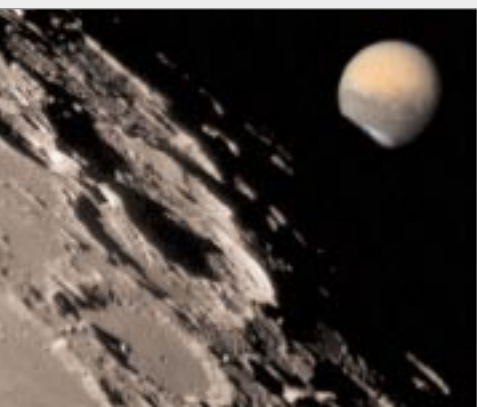
AIA's New Five-Year R&D Plan

- ▶ Implement recommendations of the Commission on the Future of the U.S. Aerospace Industry.
- ▶ Increase the NASA budget by \$34 billion.
- ▶ Bolster FAA's research, engineering, and development budget by \$3.8 billion.
- ▶ Maintain current Defense Department RDT&E funding levels at \$60-plus billion with added emphasis on aircraft propulsion, avionics, solid rocket motors, rotorcraft, and global positioning system technologies.
- ▶ Support the Joint Planning and Development Office to create a unified inter-agency R&D program.
- ▶ Support federal funding to establish research requirements for air traffic management system modernization.
- ▶ Speed transition of government research to the aerospace sector.

Further, we challenge the administration to fly a new manned launch vehicle by 2010 and increase spending toward this end by an average of \$4 billion a year.

American visionaries pioneered manned flight, a heritage that put the United States in the forefront of global aerospace achievements throughout the first century of flight.

Today, our national security and economic well-being depend on maintaining supremacy in aerospace.



Aerospace Research & Development

U.S. Aerospace Commission Endorses R&D Investments to Enable Breakthrough Technologies

The new Five-Year Research & Development Plan (2004-2008) for American aerospace, developed by the Aerospace Industries Association, has a foundation in the findings of the distinguished 2002 Commission on the Future of the U.S. Aerospace Industry.

After a year of in-depth fact finding and study, the commission, appointed jointly by the president and Congress, offered among its recommendations:

“... that the federal government significantly increase its investment in basic aerospace research, which enhances U.S. national security, enables breakthrough capabilities, and fosters an efficient, secure, and safe aerospace transportation system. The U.S. aerospace industry should take a leading role in applying research to product development.”

In its findings, the commission called for the administration and Congress to sustain significant and stable funding in order to achieve national technology demonstration goals, especially in long-term research and related RDT&E infrastructure.

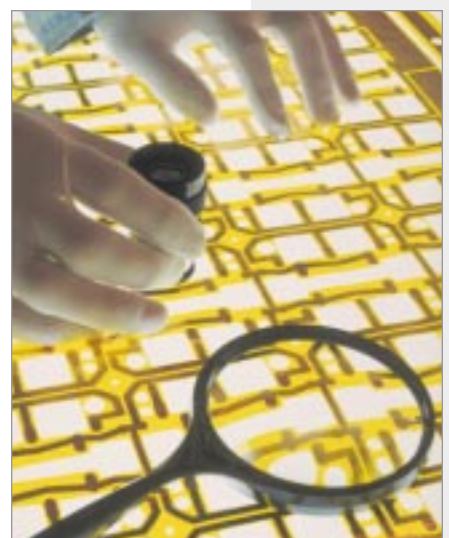
The United States has unlimited opportunities to revolutionize aerospace in the 21st century, the commission stated, opening up new markets and launching a new era of U.S. global aerospace leadership.

The nation needs to capitalize on these opportunities, and the federal government needs to lead the effort. Specifically, the report continued, it needs to invest in long-term enabling research and related RDT&E infrastructure, establish national aerospace technology demonstration goals, and create an environment that fosters innovation and provides the incentives necessary to encourage risk-taking and rapid introduction of new products and services.

The panel identified aerospace technology demonstration goals that could be adopted as a national priority. If achieved, the commission said, the goals could revolutionize aerospace in the next half century – much like the development of the jet, radar, space launch, and satellites did over the last half century.

For the nation to maintain its proud heritage and leadership in the global arena, we must remain dedicated to a strong and prosperous aerospace industry, the commission said.

A healthy and vigorous aerospace industry, commissioners agreed, holds a promise for the future by kindling a passion within our youth that beckons them to reach for the stars and thereby assure our nation’s destiny.



Aerospace Research

Civil Aviation at a Crossroads

Civil aviation is at a critical juncture in the United States.

Air transportation – the backbone of the U.S. economy – contributes approximately nine percent of the nation's gross domestic product and 11.2 million jobs.



While air travel today is recovering from the terrorist attacks of September 2001, evolutionary new aircraft are being developed that will accelerate a rebound. Recovery will be slowed, however, if America fails to invest in the aerospace innovation and infrastructure necessary to support air travel safety and growth.

The European Union has already made a commitment resulting in a civil aircraft industry that rivals ours.

Crucial for the future of U.S. aviation is development of a new, highly-automated air traffic management system that would triple air traffic capacity over the next 15 to 20 years. Among its benefits, the new system would integrate homeland security measures within, thus heightening safe and efficient travel in America's skies.

Investment in civil aviation R&D also will promote innovative technologies that would make America's aerospace systems safer to operate and more friendly to the environment.

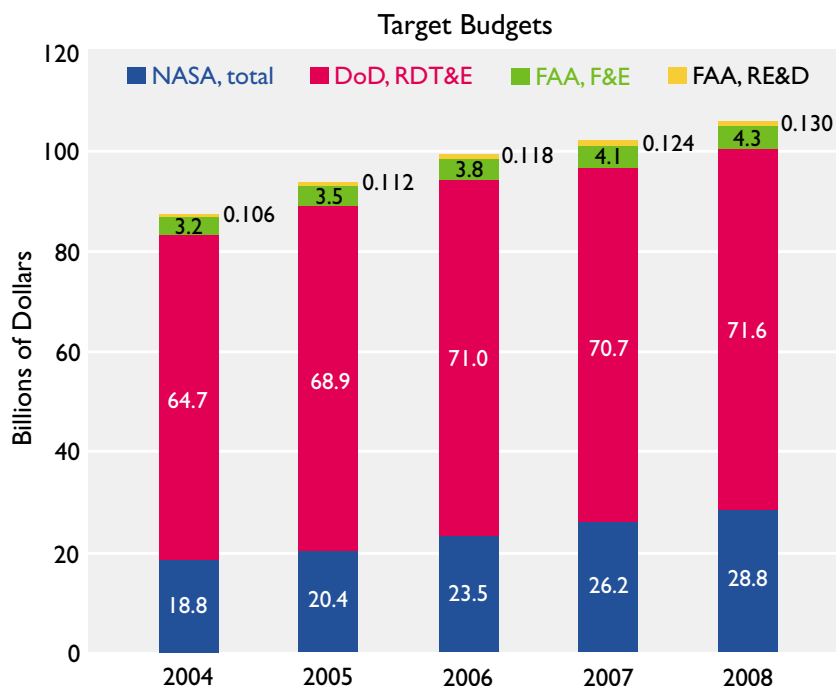
What's needed to make this happen?

NASA and FAA investment in aeronautic research and aviation system capacity must grow.

Coordination among agencies and industry needs to be fostered through the newly created Joint Planning and Development Office.

And a commitment to research and innovation must be made for America to convert the vision of a modern, capable, air traffic management system to reality.

SUMMARY: AIA Plan for R&D Funding



This chart shows proposed federal R&D funding 2004-2008, including added investment recommended by AIA — \$34 billion for NASA and \$3.8 billion for FAA.



h & Development

A New Vision for Space

President Bush set a new direction for America's space program in January 2004 when he unveiled "A Renewed Spirit of Discovery: The President's Vision for U.S. Space Exploration."

The plan calls for more robotic science missions, followed by a manned mission to the moon by 2020 as a stepping stone to sending humans to Mars. In order to accomplish this, a new crew exploration vehicle will be developed.

NASA has needed a clear mission and direction, and AIA applauds the president's visionary goals – they will breathe new life into the nation's space program.

The Commission on the Future of the U.S. Aerospace Industry in 2002 advocated a national space imperative, and AIA has been calling on the government to make a firm commitment to a new human-rated vehicle, increase the number of NASA science missions, and boost federal funding for space-related research and development (R&D).

The president's new space vision addresses all of these needs.

After years of flat or declining NASA budgets in terms of actual purchasing power, the president's 2005 budget proposal for the space agency sets a five percent increase for each of the next three years.

AIA's new Five-Year R&D Plan calls for NASA to dedicate \$20 billion towards a new human-rated transportation system that will fly by the end of the decade. NASA's plan establishes \$12 billion over the next five years for development of such a vehicle, but it won't be capable of flying astronauts until 2014.

Though NASA's plan would take four years longer to accomplish than AIA's, it goes far beyond by calling for human missions to both the moon and Mars. The plan is visionary and an exciting goal that AIA fully supports.



Aerospace R&D and A Vibrant Workforce

Robust investment in research and development plays a remarkable role in attracting new workers to aerospace careers.

Cutting-edge technologies, creative technical challenges, and next-generation programs – all with potential to change this world or go beyond to explore new worlds – are terrific inducements for young people to choose aerospace careers.

The decline in federal R&D investment in recent years has seen a parallel decrease in aerospace employment in America. The nation has lost more than 750,000 scientific, technical, production, and administrative aerospace workers during the past 14 years.

Also, the aerospace workforce is aging — 27 percent will likely retire by 2008.



The commitment we make today to aerospace design, engineering, and scientific innovations will mean all the more talent we'll have available tomorrow as we search for strategies to remain a strong and competitive nation.

Significant investment in aerospace R&D will have the biggest positive impact in influencing growth in future employment and in career choice.



Appendix B

Matrix of Findings and Recommendations

This appendix contains summaries of the findings and recommendations offered in each report. The summaries, presented in Table B-1, are organized by the following major problem areas and subareas:

- ◆ Threats to our nation
 - Reduced U.S. technological advantage and leadership
 - Declining U.S. market share and economic strength
 - Negative environmental effects
 - National security risks
- ◆ Barriers to progress—problems in our government
 - Lack of national leadership
 - Lack of clear objectives, strategy, and guidance
 - Inadequate processes for developing goals and budgeting for, managing, and evaluating R&T programs
 - Lack of well-formulated, realistic goals and timelines
 - Lack of needs, and feasibility, analysis to guide definition of R&T programs
 - Misdirected and inefficient use of resources
 - Inadequate government-wide coordination of aeronautics R&T
 - Lack of collaboration with other stakeholders
 - Weakening commitment to aeronautics R&T investment
- ◆ Barriers to progress—problems in the aviation industry
 - Limited capacity of current air transportation system and inadequate performance
 - Constraints resulting from negative impact of emissions

-
- Constraints resulting from negative impact of noise
 - Safety hazards
 - Declining RDT&E infrastructure
 - Declining workforce
 - Inadequate transition of government aeronautics technology to industry
 - ◆ Research and technology needs—air transportation system
 - Distributed communication networks and decision-support tools
 - Environmental impact of aviation
 - Human factors and human-automation interaction
 - Modeling and simulation and analytical and prediction tools
 - Non-technological factors
 - ◆ Research and technology needs—air vehicles
 - Aerodynamics
 - Propulsion systems
 - Alternative power sources
 - Cockpit displays/avionics
 - Composite materials
 - Flight control systems and software
 - Nanotechnology
 - Systems engineering, and design and integration tools
 - Aging of nonstructural components
 - Applications to specific vehicles.

Table B-1. Findings and Recommendations

Problem	5-Year R&D Plan	System in Peril	Persistent and Critical Issues	For Greener Skies	Assessing Visions and Goals	President's Commission Report	Future Flight (SATS)	Commercial Supersonic Technology	Recent Trends	Avoiding Aviation Gridlock	Commission on Aviation Safety and Security
Threats to Our Nation											
Reduced U.S. technological advantage and leadership	America is in danger of losing its position as the global leader in aerospace.		NASA's talent and test facilities have declined to the point that the nation's leadership in aeronautics is at serious risk. A vigorous national advanced aeronautical R&D program is essential to the United States sustaining and enhancing its leadership position in global air transportation. The United States should commit to (a) maintaining dominance in military aviation systems and aeronautical technology and (b) reestablishing leadership in commercial aviation and air transportation systems (including subsonic, supersonic, and short-haul aircraft). Research in the following areas will give the U.S. an enormous technological advantage: ◆ Methods that facilitate the development of cost-effective, extraordinarily reliable software and systems for safety critical operations ◆ Composite-structures research, including manufacturing techniques ◆ Propulsion systems, especially engines using alternative fuels ◆ Avionics systems and their applications.		The primacy of the U.S. aeronautics industry is an important goal missing from U.S. aeronautics goals.	Superior mobility afforded by air transportation is a huge national asset and competitive advantage for the U.S. Because of this, the U.S. must make consistent and significant improvements to our nation's air transportation system a top national priority. Increasing foreign competition, consolidation and growing retirement have led to a devastating loss of skill, experience and intellectual capital—this is a direct threat to the nation's capability to continue as a world leader. In order to remain global leaders, U.S. companies must remain at the forefront of technology development; to do this they must have access to global customers and suppliers to achieve economies of scale. Government intervention continues to distort global markets. Global U.S. aerospace leadership can only be achieved through investments in our future, including our industrial base, workforce, long-term research, and national infrastructure.		Not developing supersonic technology will jeopardize longstanding U.S. supremacy in aviation.	Maintain the superiority of U.S. aircraft and engines.	Historically the U.S. has been the leader in air traffic management and technology. However, other countries are now or soon will be moving ahead of the United States in making improvements to their aviation infrastructure. Falling behind other countries in making critical capital investments will certainly affect the international competitive position of the U.S.	Modernization of our aging airspace system is critical to maintaining our world leadership in aviation. To compete in the global economy of the 21st century, America needs a healthy, vibrant aviation industry.

Table B-1. Findings and Recommendations

Problem	5-Year R&D Plan	System in Peril	Persistent and Critical Issues	For Greener Skies	Assessing Visions and Goals	President's Commission Report	Future Flight (SATS)	Commercial Supersonic Technology	Recent Trends	Avoiding Aviation Gridlock	Commission on Aviation Safety and Security
Declining U.S. market share and economic strength		The process of improving the long-term performance of the air transportation system should start with a unified, widely endorsed, national vision that specifies goals related to industrial competitiveness.	The support provided by the federal government to civil aeronautics research and development (R&D) is not commensurate with the importance of air transportation in the nation's economy. A vigorous national advanced aeronautical R&D program is essential to the United States maintaining a strong national transportation system in support of a world class economy. Research in the following areas is likely to pay rich dividends to the U.S. economy: ◆ Methods that facilitate the development of cost-effective, extraordinarily reliable software and systems for safety critical operations ◆ Composite-structures research, including manufacturing techniques ◆ Propulsion systems, especially engines using alternative fuels ◆ Avionics systems and their applications. A major goal of U.S. government research should be to provide the basis for new private companies to enter the aircraft manufacturing market and to ensure overall global leadership for U.S. industry in aeronautics. With strong cooperation among commercial interests, universities, and government, U.S. standing in aeronautics will once again flourish. Failure to pursue such initiatives, however, will lead to further erosion in market share and a loss of global leadership for the United States in the aeronautics marketplace.			For the U.S. aerospace industry to be globally preeminent, it must be able to attract vitally needed capital at a reasonable cost. U.S. companies must have access to global customers and suppliers to achieve economies of scale. U.S. and multilateral regulations and policies should be reformed to enable the movement of products and capital across international borders on a fully competitive basis, and establish a level playing field for U.S. industry in the global marketplace. Government should promote a new business model for the U.S. aerospace industry by investing in the industry and developing policies that stimulate the flow of capital into these companies. They should use multiyear funding and contracting for procurement and R&D programs to improve program stability and use milestone budgeting for development programs. They should also expand the potential for contractors to earn higher profit margins and provide other incentives to drive and reward positive performance.		Not developing supersonic technology will significantly harm the nation's economy.	Analyze the economic implications of reduced aeronautics R&T funding before there are severe, long-term damage to national interests.	Historically the U.S. has been the leader in air traffic management and technology. However, other countries are now or soon will be moving ahead of the United States in making improvements to their aviation infrastructure. Falling behind other countries in making critical capital investments will certainly affect the international competitive position of the U.S.	Modernization of our aging airspace system is critical to our economic interests. To compete in the global economy of the 21st century, America needs a healthy, vibrant aviation industry.

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Negative environmental effects		The process of improving the long-term performance of the air transportation system should start with a unified, widely endorsed, national vision that specifies goals related to environmental compatibility.		The U.S. government should carry out its responsibilities for mitigating the environmental effects of aircraft noise and emissions with a balanced approach. The environmental impact of any industry, including aviation, would be reduced if equipment manufacturers, service providers, and consumers directly faced the full cost of their activities, including environmental costs.					Ensure the long-term environmental compatibility of the aviation system.		
National security risks		The process of improving the long-term performance of the air transportation system should start with a unified, widely endorsed, national vision that specifies goals related to security.	The support provided by the federal government to civil aeronautics research and development (R&D) is not commensurate with the importance of air transportation in the nation's security and the international war on terrorism. A vigorous national advanced aeronautical R&D program is essential to the United States maintaining homeland security and winning the war on terrorism. Methodologies that facilitate the development of cost-effective, extraordinarily reliable software and systems for safety critical operations should receive the strongest possible support, as they will enhance national security.						Analyze the national security implications of reduced aeronautics R&T funding before there are severe, long-term damage to national interests.		Cost alone should not become dispositive in deciding aviation safety and security rulemaking issues. They are but one input for decision-making; nonquantifiable security benefits should be included in the analysis of proposals. The health and vibrancy of aviation depends on improved levels of security. Establish a joint government-industry research and development program whose mission will be to accelerate research and development to enhance the security of air travel. Establish an interagency task force to assess the potential use of surface-to-air missiles against commercial aircraft, as well as surveillance methods and countermeasures. The federal government should consider aviation security as a national security issue, and provide substantial funding for capital improvements.

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Barriers to Progress—Problems in Our Government											
Lack of national leadership		Establish air transportation as a national priority with strong, focused leadership. Strong national leadership should coordinate the effort to develop a coherent set of operational concepts to support a vision for the air transportation system in 2050. The process of developing operational concepts provides an opportunity to achieve national consensus among various stakeholders at a level of detail that permits more focused agreement and planning. Federal leadership should be exercised by an agency or office with (1) the responsibility, authority, and financial resources necessary for defining air transportation system architectures through a centralized planning function, (2) an understanding of the interactions among system performance parameters, demand and economic factors, and (3) the credibility and objectivity to garner the support of other AT stakeholders.		Success requires commitment and leadership at the highest level. The following lesson, learned since the advent of jet-powered aircraft, should be used to formulate and evaluate strategies for reducing the environmental effects of aviation: success is not easy—it requires government support and federal leadership in research and development of new technology.		The United States should boldly pioneer new frontiers in aerospace technology, commerce and exploration. Transforming the U.S. air transportation system as a national priority requires strong federal leadership. The federal government should create a national aerospace consensus that supports broader national security and economic policies, goals and objectives.					

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Lack of clear objectives, strategy, and guidance		The process of improving the long-term performance of the air transportation system should start with a unified, widely endorsed, national vision that specifies goals in each key area of interest to the commercial aviation community. Visions should establish goals related to safety and security, capacity, environmental compatibility, satisfaction of consumer needs, and industrial competitiveness. It should include a clear set of guiding principles and a strategy for overcoming transitional issues. The federal government, working with other stakeholders, should develop a coherent set of operational concepts to support a vision for the air transportation system in 2050. Concepts should be continuously evaluated and iterated with national leadership to coordinate these efforts.		Success requires a national strategy and plan.	Committee concluded that U.S. visions and goals consistently overlook a clear set of guiding principles, and a strategy for overcoming transitional issues.	The federal government should create a national aerospace consensus that supports broader national security and economic policies, goals and objectives. The nation needs a national aerospace policy. The nation does not have bold aerospace technology goals to focus and sustain research investment.			Clearly define national objectives for aeronautics R&T.	The FAA and the aviation industry must develop a strategic plan to improve safety, with specific priorities based on objective, quantitative analysis of safety information and data. Presently, there is no agreed upon safety improvement strategy to prioritize all the previous recommendations that have been made and develop a comprehensive plan to implement them.	

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Inadequate processes for developing goals and budgeting for, managing, and evaluating R&T programs		The federal government, working with other stakeholders, should develop a coherent set of operational concepts to support a vision for the air transportation system in 2050. Operational concepts should guide long-term research and concepts should be continuously evaluated and iterated; the process of developing these concepts provides an opportunity to achieve national consensus among various stakeholders at a level of detail that permits more focused planning. Air transportation system technology planning and development should be done in the context of a process driven by the needs of system users and the nation as a whole.		The U.S. government should carry out its responsibilities for mitigating the environmental effects of aircraft noise and emissions with a balanced approach that includes interagency cooperation and investing in research and technology development in close collaboration with the private sector and university researchers. This plan should coordinate agency research/ budgets/expenditures with national goals and international standards, periodically reassess environmental goals and related research programs to ensure they reflect current understandings, take advantage of unique expertise of both government and industry, reallocate funds in accordance with long-term goals, shifting resources from short-term fixes to changes at the source of the problem, and support international assessment of the effects of emissions and alternatives for limiting emissions.	Committee concluded that U.S. visions and goals consistently overlook a description of the overall process for developing and achieving a widely endorsed long-term vision for the air transportation system.	Federal government needs a streamlined innovation process to ensure that the U.S. aerospace RDT&E infrastructure is right-sized, state-of-the-art, affordable, and supports joint government-industry use in achieving national objectives. Government should establish an integrated federal planning, budgeting, and program management process where every federal department and most agencies create an Office of Aerospace Development to prioritize and promote aerospace activities within their organizations and the public; OMB establishes a Bureau of Aerospace Management to develop and implement an aerospace strategic plan and prepare aerospace sector budget; White House should establish an aerospace policy coordinating council to develop and implement national aerospace policy consistent with national security and economic goals; Congress should create a Joint Committee on Aerospace to coordinate legislatively.		In order to advance work on a highly integrated, actively controlled airframe propulsion system, NASA should create a new culture of collaboration with a focus on integrating the design of mechanical systems and electrical systems and software development. Interdisciplinary teams should be formed to address APSE problems, between groups responsible for guidance and control systems and structural-mode control laws.		The Commission recommends that FAA form a joint industry/FAA safety council to periodically review safety priorities and the implementation of a strategic safety plan; the Commission also recommends that there be an annual public safety conference, with workshops addressing safety initiatives, as well as the continuation of an oversight body established by the Aviation Safety Plan to ensure that high priority safety initiatives are tracked and receive appropriate attention.	
Lack of well-formulated, realistic goals and timelines		The future vision for air transportation system should be supported by research and technology goals leading to improved performance. Measurable long-term targets supported by sound analyses should be established to assess progress toward the goals.		Present efforts are operating with ambitious goals, unrealistic timetables for meeting them and diminishing resources. Additional technological advances now possible could move most objectionable noise within airport boundaries. However, the goal is unlikely to be achieved by NASA’s target date of 2022. NASA funding to achieve its goals for reducing CO2 and NOx emissions is insufficient to reach the specified milestones on time. NASA and the FAA should develop clear metrics for assessing the effectiveness of NASA and FAA noise-modeling efforts.						FAA safety programs need to become performance-oriented. The FAA must establish performance measures and milestones to focus resources and hold the agency’s safety management accountable to make improvements.	

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Lack of needs, and feasibility, analysis to guide definition of R&T programs		Air transportation system technology planning and development should be done in the context of a process driven by the needs of system users and the nation as a whole. Valid research requirements for the air transportation system depend on understanding how the U.S. air transportation system of the future will fit into both the national intermodal system and the international air transportation system. The process of improving the long-term performance of the air transportation system should start with a unified, widely endorsed, national vision that specifies goals related satisfaction of consumer needs.			The satisfaction of consumer needs is an important goal missing from U.S. aeronautics goals.		For the SATS concept to be plausible, many assumptions must hold. Many technical and practical challenges await the development and deployment of SATS technologies; SATS concept does not address root causes of congestion, has limited appeal to consumers, and has the potential for undesirable outcomes. The prospects of environmental gains from a SATS oriented toward more fuel-intensive vehicles flying with fewer occupants at low altitudes are not apparent. Using a single and definitive vehicle concept to guide research and development could inhibit the evolution of alternative outcomes that may result from technological opportunities and social and economic need. NASA should join with other government agencies, led by the DOT, in undertaking forward-looking studies of civil aviation needs and opportunities to ensure that they are addressed appropriately through government-funded technology research and development. Working with FAA, National Transportation Safety Board, and other government agencies, NASA should gain a better understanding of these needs and how to structure aeronautics research and development to help meet them. NASA should prioritize the capabilities and technologies that are now being pursued in the SATS program according to a clearly defined set of civil aviation needs that these capabilities and technologies can help meet.		Gather continuing input from industry, government, military and commercial technology users.		

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Misdirected and inefficient use of resources				Federal expenditures to reduce noise should be reallocated to shift some funds from local abatement, which provides near-term relief for affected communities, to research and technology that will ultimately reduce the total noise produced by aviation.			Committee endorses much of the technological research and development contained in the SATS program, as well as the approach of using NASA resources and expertise to leverage and stimulate private-sector investment in aeronautics research and development.	NASA should allocate most of the available resources on goals and objectives relevant to aircraft with cruise speeds of less than Mach 2 (NRC concluded in 1997 that focus on Mach 2.4 was too aggressive and not justified by the business analysis).			
Inadequate government-wide coordination of aeronautics R&T	Support the Joint Planning and Development Office to create a unified inter-agency R&D program.	Federal agencies involved in modeling and simulation of the air transportation system should make complementary use of data and analysis to improve decision making and eliminate redundancies. Federal agencies that support research in aviation system models should improve their coordination.	The Federal Aviation Administration (FAA) and NASA in a synergistic partnership with the DoD should be given the mandate to create a world-class national aeronautics research program. The establishment of a Joint Planning Office (JPO) is a positive first step toward greater inter-agency interaction and productivity. This initiative needs to be closely watched to assess its effectiveness, and appropriate steps taken to ensure its success or to seek alternative means, if necessary.	The U.S. government should carry out its responsibilities for mitigating the environmental effects of aircraft noise and emissions with a balanced approach that includes interagency cooperation. Interagency coordination on aircraft noise research should be enhanced by ensuring that the members of the Federal Interagency Committee for Aircraft Noise have budget authority within their own organizations to implement a coordinated strategy for reducing aviation noise. To reduce conflicts between the growth of aviation and environmental stewardship, NASA, the FAA, and the Environmental Protection Agency (EPA) should augment existing research by developing specific programs. (See Environmental Research for more detail on programs).		Deploy a new, highly automated air traffic management system via a multiagency task force with the leadership to transform our air transportation system. This task force should be immediately assigned the leadership role to establish a Next Generation Air Transportation System Joint Program Office that brings together FAA, NASA, DoD, DHS, NOAA, and others. Within a year, the Joint Program Office should present a plan to the Administration and Congress outlining the overall strategy, schedule and resources needed to develop and deploy the nation's next generation air transportation system. Defense technology developed by the U.S. military should be adapted and transitioned into other government applications that would significantly enhance the capacity of our air traffic management system.	NASA should join with other government agencies, led by the DOT, in undertaking forward-looking studies of civil aviation needs and opportunities to ensure that they are addressed appropriately through government-funded technology research and development; Working with the FAA, National Transportation Safety Board, and other government agencies with operational and technological expertise, NASA should gain a better understanding of these needs and how to structure aeronautics research and development to help meet them.	Activities should be coordinated with similar efforts supported by other federal agencies (including DARPA).	Establish overarching organization for the coordination of national aeronautics R&T activities (values, resources, efficiencies), and among NASA, DoD, FAA, industry and academia.		Establish an interagency task force to assess the potential use of surface-to-air missiles.

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Lack of collaboration with other stakeholders		Federal agencies that support research in aviation system models should involve industry and academic partners, establishing criteria for maintenance and validation of models, identifying critical models and making them available to users inside/outside government, and ensuring that modeling results are used appropriately by decision-makers.	In order to safely and economically incorporate new concepts and technologies into commercial and military aircraft it is essential to keep partnerships with the nation's universities and industries vigorous and healthy. With strong cooperation among commercial interests, universities, and government, U.S. standing in aeronautics will once again flourish.	U.S. government should carry out its responsibilities for mitigating the environmental effects of aircraft noise and emissions with a balanced approach that includes interagency cooperation and investing in research and technology development in close collaboration with the private sector and university researchers. The plan should support international assessment of the effects of emissions and alternatives for limiting emissions.		United States must work cooperatively with other countries via ICAO, World Radio Conference and other multilateral forums to ensure interoperable technology and standards; U.S. government must coordinate policies among agencies and commit the resources needed for active participation in international negotiations. Create incentives and an environment that foster public-private partnerships. NASA and other agencies need to work with industry and academia to create new partnerships and transform the way they do business.	NASA must continue to involve the FAA and state/local agencies in evaluation of this technology program. NASA should work closely with commercial developers and users to be sure the technologies it pursues are practical from the standpoint of commercialization.	NASA should work closely with engine and airframe manufacturers and other industries, agencies, universities engaged in developing integrated design tools to develop a comprehensive plan for meeting needs.	Establish overarching organization for the coordination of national aeronautics R&T activities (values, resources, efficiencies), and among NASA, DoD, FAA, industry and academia. Gather continuing input from industry, government, military and commercial technology users'. Examine successful collaborative programs (i.e. AGATE, NRTC, IHPTET) to identify characteristics.	Government/industry partnerships on safety need to be strengthened. The Commission recommends that the FAA take necessary steps to facilitate or initiate joint government/business round tables in order to improve safety abroad. The Commission recommends that FAA form a joint industry/FAA safety council to periodically review safety priorities and the implementation of the strategic safety plan.	Establish a joint government-industry research and development program whose mission will be to accelerate research and development to enhance the security of air travel. A strong government-industry partnership is needed to develop and integrate the research, standards, regulations, procedures, and infrastructure needed to support the aviation system of the future. The FAA has applied this approach successfully to cooperative research projects with NASA in the development of advanced air traffic technologies. The Commission encourages these agencies and others to expand their cooperative efforts in aviation safety research and development.

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Weakening commitment to aeronautics R&T investment	Increase NASA budget by \$34 billion (from FY04-FY08) and the NASA Aeronautics budget by \$1.7 billion. Support federal funding to establish research requirements for air traffic management system modernization.		The Europeans and Canadians have recognized the essential role that federally funded basic research plays in support of the private sector. For many years this has been true of the U.S. as well, but in recent years that commitment has weakened significantly. A vigorously funded aerospace R&D program at the national level will make new industrial companies and employment opportunities possible. The Committee believes that the aeronautics portion of the NASA budget should be increased to \$2.1 billion (which includes full cost pricing) over the next eight years, with a long-term target of attaining a level of 10 percent of the total NASA budget. Achieving this target would reestablish aeronautics funding, as a percentage of the NASA budget, at its pre-1990 level. A team of experts from industry, government, and academia should be immediately chartered to identify the infrastructure requirements for a robust national aeronautical R&D program aimed at developing a new generation of advanced aeronautical vehicles. In parallel, funded R&D adequate to sustain or build this infrastructure should be identified. Flight demonstrations (jointly funded by DoD and NASA) should be sustained at an annual budget level sufficient to determine the integrated performance of promising and dramatic new emerging technology opportunities.	One of the most significant impediments to reducing the impact of aviation noise (or emissions) is the low level of research and development funding. Continuation of ongoing technology research will reduce fuel consumption per revenue-passenger-kilometer by about 1 percent per year over the next 15 to 20 years. During the same time, the demand for air transportation services is expected to increase by 3 to 5 percent per year. An aggressive, broad-based technology program that encompasses propulsion systems, the airframe, and operational systems and procedures could significantly close this gap. Existing allocations of research funding and funding trends within NASA and the FAA do not support such a program. NASA funding to achieve its goals for reducing CO2 and NOx emissions is insufficient to reach the specified milestones on time. Little or no funding is available for research related to other emissions, such as hydrocarbons, particulates, and aerosols, which may also have significant effects on the atmosphere locally, regionally, or globally.		Government investments in long-term research have not kept pace with the changing world. Increase public funding for long-term research and RDT&E Infrastructure in information technology, propulsion and power, human factors, nanotechnology, noise and emissions, breakthrough energy sources. Additional government investment in long-term noise and emissions research is imperative.		NASA appears to be changing its technology investment strategy so that it reaches TRLs of only 3 or 4. At a time when manufacturers require TRLs of 6 or higher to embrace complex new technologies, NASA should invest enough to advance the technologies listed to Technology Readiness Levels (TRL) of 6.	Stop reductions in government support of aeronautics R&T, as continued reductions will damage personnel base and infrastructure required to remain competitive in military and industry.	The FAA's six year requirements estimate recommended more than doubling RE&D funding to a level of \$420 million in FY2002 from \$208 million in 1997; this is a satisfactory level of funding assuming cooperative leveraging of NASA, DoD and industry research (NASA is proposing to spend about \$500 million over the next five years on aviation safety research). The Commission supports NASA's role to develop breakthrough safety technologies while the FAA works to improve safety today.	

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Barriers to Progress—Problems in the Aviation Industry											
Limited capacity of current air transportation system and inadequate performance	Support federal funding to establish research requirements for air traffic management system modernization.	The most critical long-term issue facing the air transportation system is the challenge of increased demand. Business as usual, in the form of continued evolutionary improvements is unlikely to meet needs in the next 25–50 years; the likely result is an air transportation system where growth in demand is greatly curtailed by under-capacity in the air transportation system. Developing meaningful and useful operational concepts stemming from a broadly defined vision of the air transportation system in a critically important task in the process of improving the performance of the system. Improvements in aircraft performance are critical to achieving necessary improvements in almost every aspect of the overall performance of the air transportation system.				Establish National Technology Demonstration Goals for 2010 to (1) demonstrate an automated and integrated air transportation capability that would triple capacity by 2025, and (2) reduce transit time between any two points on Earth by 50%. Transform the U.S. air transportation system as a national priority (Operational Evolution Plan should be fully funded but it does not give nation sufficient capacity to meet long-term demand). Deploy a new, highly automated air traffic management system via a multiagency task force with the leadership to transform our air transportation system. Streamline the airport and runway development process (FAA and other agencies should expedite new runway and airport development as a national priority). Develop a next generation communication, navigation, surveillance and reconnaissance capability.	Infrastructure limitations at small airports are likely to present large obstacles to SATS deployment.		Improve the efficiency and cost-effectiveness of the global air transportation system.	Gridlock is near and it will be expensive. Rapidly growing demand combined with a reduction in capacity, as the result of continued reliance on outdated equipment, will bring our nation's aviation system to gridlock soon after the turn of the century.	Modernization of our aging airspace system is critical to the safety of the traveling public, to maintaining our world leadership in aviation, and to our economic interests. The FAA should develop a revised NAS modernization plan within six months (from 1997) that will set a goal of the modernized system being fully operational nationwide by the year 2005. The FAA should develop plans to ensure that operational and airport capacity needs are integrated into the modernization of the NAS; the FAA should immediately develop a NAS operational plan and plan for modernization of U.S. airports that is consistent with modernization of the NAS. The U.S. government should ensure the accuracy, availability and reliability of the GPS system to accelerate its use in NAS modernization and to encourage its acceptance as an international standard for aviation.
Constraints resulting from negative impact of emissions		Further develop, in support of long-term operational concepts, technologies for moderating and abating the impact of emissions.		Environmental concerns will increasingly limit the growth of air transportation in the 21st century unless vigorous action is taken to augment current research and technology related to the environmental impacts of aviation. Fuel consumption is a key indicator for assessing trends in emissions. The aviation industry is growing and the use of aviation fuel is increasing at a rate comparable to that of other uses of fossil fuels.		Establish a National Technology Demonstration Goals for 2010 to reduce aviation emissions by 90%. Additional government investment in long-term emissions research is imperative, since this constrains capacity growth (includes new energy sources, vehicle design, active/passive surface control).	Emissions concerns at small airports are likely to present large obstacles to SATS deployment.	Economically viable supersonic commercial aircraft with cruise speed higher than Mach 2 requires additional, significant research and technology development to overcome climate effects and depletion of atmospheric ozone caused by emissions of water vapor and other combustion by-products in the stratosphere (this is unlikely to mature enough to enable operational deployment of such an aircraft in 25 years).			

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Constraints resulting from negative impact of noise		Further develop, in support of long-term operational concepts, technologies for moderating and abating the impact of noise.		Environmental concerns will increasingly limit the growth of air transportation in the 21st century unless vigorous action is taken to augment current research and technology related to the environmental impacts of aviation. The cost of aviation noise is significant and growing. Aviation noise reduces property values, contributes to delays in expanding airport facilities, and prompts operational restrictions on existing runways that increase congestion, leading to travel delays, high airline capital and operating costs, and high ticket prices. Achieving NASA's current goal (for 2022) may not fully alleviate the constraints that noise places on the aviation industry because of potential changes in the public's perception of the importance of a low-noise environment to quality of life.		Establish a National Technology Demonstration Goals for 2010 to reduce aviation noise by 90%. Additional government investment in long-term noise research is imperative, since this constrains capacity growth (includes new energy sources, vehicle design, active/passive surface control).	Noise concerns at small airports are likely to present large obstacles to SATS deployment.	Continued advances are necessary in flight control systems, operational procedures, aerodynamic, and propulsion systems for noise abatement during takeoff and landing. Economically viable supersonic commercial aircraft with cruise speed higher than Mach 2 requires additional, significant research and technology development to overcome noise suppression at acceptable propulsion system weight (this is unlikely to mature enough to enable operational deployment of such an aircraft in 25 years).			

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Safety hazards		The process of improving the long-term performance of the air transportation system should start with a unified, widely endorsed, national vision that specifies goals related to safety.				Establish a National Technology Demonstration Goal for 2010 to reduce the aviation fatal accident rate by 90%.		In order for industry to take on the development of an economically viable, environmentally acceptable commercial supersonic aircraft, continued advances are necessary in: ◆ Approaches for mitigating safety hazards that may be associated with long-term exposure to radiation at altitudes above 45,000 feet. ◆ Approaches for mitigating safety hazards that may be associated with cabin depressurization at altitudes above about 40,000 feet.	Improve the safety of the global air transportation system.	The introduction of highly reliable jets into commercial aviation resulted in a dramatic, multifold reduction in the accident rate, but since that time the accident rate has remained virtually unchanged. A flat accident rate coupled with the anticipated healthy growth in aviation will lead to a significant increase in the number of absolute accidents. The accident rate must be reduced significantly. The recent White House Commission on Aviation Safety and Security recommended the adoption of a goal of an 80% reduction in the fatal accident rate within 10 years. The Commission believes this is a reasonable target upon which to focus accident reduction policies. Reducing the incidence of runway incursions should be included as a priority in the strategic plan. Government and industry should expand on their programs to improve aviation safety in other parts of the world. Aviation safety programs in industry and government need to be improved by establishing more effective safety risk management programs. This should include self-audit programs within aviation companies, protecting and sharing safety information in nonpunitive ways, and encouraging research to support these activities. The Commission believes that there needs to be continued attention given to improving the chances of passengers and crew surviving an aircraft accident.	To compete in the global economy of the 21st century, America needs a healthy, vibrant aviation industry. In turn, the health and vibrancy of aviation depend on improved levels of safety. Modernization of our aging airspace system is critical to the safety of the traveling public. Government and industry should establish a national goal to reduce the aviation fatal accident rate by a factor of five within ten years (from 1997) and conduct safety research to support that goal; Achieving this goal will require the combined efforts of government and industry focused on three objectives: (1) preventing equipment malfunctions, (2) reducing human-caused mishaps, and (3) ensuring separation between aircraft and other air or ground hazards. The Commission urges NASA, which has considerable expertise and resources in the area of safety research, to expand its involvement in the promotion of aviation safety. Cost alone should not become dispositive in deciding aviation safety and security rulemaking issues. They are but one input for decision-making; nonquantifiable safety benefits should be included in the analysis of proposals.

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Declining RDT&E infrastructure			NASA's network of test facilities and research aircraft has declined. The need to retain an affordable ground-testing infrastructure for commercial and DoD users must emerge as a national priority; in addition to maintaining current facilities, strategic investments in new wind tunnel and other major ground and flight test facilities must be made to provide state-of-the-art capability. A team of experts from industry, government, and academia should be immediately chartered to identify the infrastructure requirements for a robust national aeronautical R&D program aimed at developing a new generation of advanced aeronautical vehicles; In parallel, funded R&D adequate to sustain or build this infrastructure should be identified. Long-term damage to our aeronautics capability can be mitigated by an aggressive revitalization of an Xplanes program supporting aeronautics R&D (this would include modifications to existing test aircraft to evaluate advanced concepts in flight). Essential ground and flight-testing capabilities must be preserved and new, more productive capabilities should be developed, including physical infrastructure, so that new generations of advanced aircraft can be designed safely to be competitive in the world market.			Global U.S. aerospace leadership can only be achieved through investments in our future, including our long-term research and national infrastructure.		Flight experiments will play an important role in the development of new concepts, and methods for more efficient flight tests, including the development of sensors for flow diagnostics, will be especially important. New supersonic wind tunnel capability may also be needed.	Increasing globalization does not affect requirements for facilities and other resources necessary for effective R&T; continued investment is necessary.		

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Declining work-force			NASA's talent and experience in aeronautics research has declined. There are opportunities for new industrial companies and employment opportunities to emerge based upon technological advances made possible by a vigorously funded aerospace R&D program at the national level. Federally funded programs specifically designed to attract and retain the best young people in the aeronautics community should be established and supported. NASA fellowships during the Apollo program years and United States Air Force (USAF) "Palace Knight" programs, for example, were effective, but need current counterparts. The nation should guard against a loss of technical expertise in the critical field of wind tunnel testing.			Increasing foreign competition, consolidation and growing retirement have led to a devastating loss of skill, experience and intellectual capital in the industry. This is a direct threat to the nation's capability to continue as a world leader. The nation must immediately reverse the decline in a scientifically and technologically trained U.S. aerospace workforce by creating an interagency task force that develops a national strategy on the aerospace workforce to attract attention and by establishing lifelong learning, individualized instruction, and increased emphasis on math and science as key elements of educational reform. Global U.S. aerospace leadership can only be achieved through investments in our future, including our workforce.					
Inadequate transition of government aeronautics technology to industry	Speed transition of government research to the aerospace sector.			Some of the most significant impediments to reducing the impact of aviation noise (or emissions) include long lead times for technology development and adoption, long lifetimes of aircraft in the fleet, high development and capital costs in aerospace, and high residual value of the existing fleets. U.S. plan should expedite deployment of new technologies by maturing them to a high readiness level and providing incentives for manufacturers. NASA and other agencies should sustain the most attractive noise reduction research to a technology readiness level high enough (i.e., technology readiness level 6, as defined by NASA) to reduce the technical risk and make it worthwhile for industry to complete development and deploy new technologies in commercial products, even if this occurs at the expense of stopping other research at lower technology readiness levels.		Establish a National Technology Demonstration Goals for 2010 to reduce the transition time from technology demonstration to operational capability from years and decades to weeks and months. Accelerate the transition of government research to the aerospace sector. Government should assist industry by providing them with insight into its long term research programs, creating incentives for working together, and working jointly with industry to set goals, milestones, and a process for governance. Shift from product to process certification in order to keep up with technological innovations. Solve the airborne equipment problem via additional federal funding.	NASA should work closely with commercial developers and users to be sure the technologies it pursues are practical from the standpoint of commercialization.	In order to allow promising technologies to make the transition from lab to the marketplace, NASA should invest enough to advance the technologies to Technology Readiness Levels (TRL) of 6.			

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Research and Technology Needs—Air Transportation System											
Distributed communication networks and decision-support tools		Further develop the following, in support of long-term operational concepts: ◆ Technologies that support distributed, collaborative decision-making ◆ Automation technologies, automated decision aids, and information systems for communication, visualization, situation assessment, prediction ◆ Technologies for predicting or sensing the magnitude, duration, and location of wake vortices and the potential to reduce separation standards without compromising safety. In order to understand the challenges of designing complex human-integrated systems, research is needed in geographically distributed activities such as coordinated decision making and planning, that are mediated by computers.				Increase public funding for long-term research and RDT&E Infrastructure in integrated networks. Additional research in integrated networks is a primary contributor to reaching the goals to triple capacity of air transportation system by 2025 and reduce technology transfer time. It will also help support goals to reduce aviation noise and emissions, reduce fatal accident rate, and reduce transit time.				In order to prevent runway incursions, the Commission is encouraged by the initial agency plans to study the feasibility of deploying a less costly Airport Movement Area Safety System (AMASS) type of coverage. In addition, NASA and FAA research has developed cockpit and ATC displays which present moving map and virtual heads-up presentations of airport taxi-routes and traffic during low visibility. This technology offers great promise for the future. Improved weather training, as well as improved weather detection and display technologies for aircraft and air traffic controllers should be part of a strategic plan for safety improvement.	

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Environmental impact of aviation		Federal agencies should continue to support research in environmental consequences of aircraft noise and emissions to better understand consequences and support the establishment of better informed priorities and goals for reduction.		Environmental concerns will increasingly limit the growth of air transportation in the 21st century unless vigorous action is taken to augment current R&T related to aviation 's environmental impacts. NASA should support additional research on environmental effects of aviation to ensure technology goals are appropriate and to validate that regulatory standards will effectively limit potential environmental and public health effects of aircraft emissions, while eliminating uncertainties that could lead to unnecessarily strict regulations. The formulation of technological strategies to reduce the environmental impacts of aviation is hampered by significant uncertainties. NASA and the FAA, in collaboration with other stakeholders, should support research to establish more clearly the connection between noise and capacity constraints. NASA should continue to take the lead in supporting federal research to investigate relationships among aircraft emissions and environmental effects of aviation to ensure that technology goals are appropriate. NASA, FAA, and Environmental Protection Agency (EPA) should augment research by developing programs aimed at the following topics: determining which substances identified by the EPA as hazardous air pollutants are contained in aircraft emissions and need to be further reduced; understanding and predicting atmospheric response to aircraft emissions as a function of time on local, regional, and global spatial scales; and exploring the suitability of alternate sources of energy for application to aviation, taking full account of safety and operational constraints.							

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Human factors and human-automation interaction		In order to understand the challenges of designing complex human-integrated systems, research is needed in human factors and human automation interactions and the impact of newly automated functions and changes in human roles.				Increase public funding for long-term research and RDT&E Infrastructure in human factors. Additional research in this area is a primary contributor to reaching the goals to triple capacity of air transportation system by 2025 and reduce fatal accident rate. It will also help support goal to reduce technology transfer time.		Research in airframe configurations to reduce sonic boom intensity should be supported by research in analytical tools to quantify the human responses to shaped waves.		Any strategy to bring about a dramatic reduction in the accident rate must include government and industry programs that strive to bring down the incidence of human error (which was the cause of 72% of commercial jet accidents worldwide over the last 10 years). The Commission recommends that the strategic plan for accident reduction develop new pilot training programs that better enable pilots to recover from a loss of control of their aircraft. A strategic plan for accident reduction should call for improved training in following standard procedures in landing and approach. Improved weather training for air traffic controllers should be part of a strategic plan for safety improvement. Human performance analyses and improvement programs applied to the aircraft maintenance area would help reduce the accident rate and should be part of the strategic safety plan.	Government and industry aviation safety research should emphasize human factors and training. The FAA, NASA, the DoD and the aviation industry jointly developed a National Aviation Human Factors Plan that describes a strategic approach to solving the problem of human-caused mishaps. Two additional studies, one by FAA and one by industry and government representatives, also identify a wide range of safety issues. The Commission acknowledges the importance of all three of these reports and urges the immediate development of an implementation plan.

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Modeling and simulation and analytical and prediction tools		The federal government should support research in the following areas related to system modeling: interoperability of multiple models, modeling methods suitable for safety analysis (such as systems theory), modeling demand and demand allocation, methods and standards for validating models and suites of models, understanding how to connect models to form a suite of system models, and understanding the role of humans in the aviation system of the future. Federal agencies should continue to support research in analytical tools to reduce the need for costly hardware testing.	Research on new and more effective prediction methodologies are sorely needed to meet the challenges of complex design decisions.			Additional research in modeling/simulation and sensors is a primary contributor to reaching the goals to triple capacity of air transportation system by 2025 and reduce technology transfer time. It will also help support goals to reduce aviation noise and emissions, reduce fatal accident rate, and reduce transit time.		New analysis and synthesis tools, including aeroelastic modeling approaches are required. The ability of national simulation facilities to deliver high-fidelity manned simulations of highly flexible aircraft may need to be upgraded. The uncertainty of results produced by current atmospheric models is still substantial. Continued development of these models is crucial to ensure that the environmental impacts of a future fleet of commercial supersonic aircraft can be accurately predicted. Research in airframe configurations to reduce sonic boom intensity should be supported by research in analytical tools to quantify atmospheric effects on low-boom shaped signatures, the persistence of signatures in the atmosphere, and human responses to shaped waves.		Costs are a significant constraint to the implementation of Flight Operations Quality Assurance (FOQA) programs. The FAA and NASA are collaborating with United and Alaska Airlines to develop tools that will make data analysis more affordable and effective. The Commission applauds and encourages these research efforts. Whenever possible, FOQA data should become part of safety risk management programs. Ongoing research by the FAA, NASA, and the aviation industry, and the revolution in information technology, are now beginning to make it possible to use flight data recorder data in ways not dreamed possible before. This could become a new method for the aviation community to identify and fix problems before they become accidents and for the FAA to oversee and improve the aviation system at a fraction of today's costs.	The FAA should develop better quantitative models and analytic techniques to inform management decision-making and give insight into the systemwide consequences of alternative courses of action.
Nontechnological factors		Federal government should support research to develop improved processes and methods in the following nontechnology areas: assessment of economic factors that influence the demand for and supply of air transportation services and the decisions made by organizations and individuals, modification of regulations, certification requirements and operating procedures, prediction and resolution of conflicting objectives of different stakeholders in the air transportation system, and understanding societal concerns about noise and emissions.		To support the formulation of environmental goals and air transportation policies, government and industry should invest in comprehensive interdisciplinary studies that quantify the marginal costs of environmental protection policies, the full economic benefits of providing transportation services while reducing the costs (in terms of noise, emissions, and congestion), and the potential of financial incentives to encourage the development and use of equipment that goes beyond regulatory standards.				In order for industry to take on the development of an economically viable, environmentally acceptable commercial supersonic aircraft, continued advances are necessary in certification standards that encompass all new technologies and operational procedures to be used with commercial supersonic aircraft.			

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Research and Technology Needs—Air Vehicles											
Aerodynamics		Federal agencies should continue to support re-search in nontraditional aircraft configurations to improve productivity and efficiency and reduce noise and emissions. Agencies should also continue to support research in passive and active control of laminar and turbulent flow on aircraft wings to increase efficiency and performance.		An aggressive, broad-based technology program that encompasses the airframe could significantly close the gap between demand and environmental compatibility.		Increase public funding for long-term research and RDT&E Infrastructure in vehicle design and active/passive control. Additional research in this area will be a major contributor to reducing noise and emissions and will also help reduce transit time.		Augment current research with new, focused efforts (or significant expansion of effort) in improved aerodynamic performance (through laminar flow and advanced airframe configurations to reduce sonic boom intensity); meeting L/D goals should remain focus of aerodynamic research. Future research to support improved aerodynamic performance should include techniques to predict and control transition from laminar flow to turbulent flow.			
Propulsion systems		Federal agencies should continue to support re-search in nontraditional propulsion concepts and technologies. Federal agencies should continue to support re-search in low emissions combustor technology to reduce emissions of NO and reduce emissions produced by engines with high pressure ratios. Federal agencies should continue to support re-search in high-temperature engine materials and advanced turbomachinery to improve efficiency and reduce noise.	Federal programs need to recognize that retaining national leadership in aircraft propulsion demands a program balanced between near term needs, driven by market forces, and longer-term investments required to achieve transformational national capabilities.	An aggressive, broad-based technology program that encompasses propulsion systems could significantly close the gap between demand and environmental compatibility.		Increase public funding for long-term research and RDT&E Infrastructure in propulsion and power. Additional research in this area will be a primary contributor to reaching the goals to reduce noise and emissions and reduce transit time. It will also help reach the goal of reducing technology transfer time.		Augment current research with new, focused efforts (or significant expansion of effort) in variable cycle engines for low thrust-specific fuel consumption, high thrust-weight ratio and low noise. In order for industry to take on the development of an economically viable, environmentally acceptable commercial supersonic aircraft, continued advances are necessary in propulsion systems with low noise during takeoff and landing, and engine materials for long life at high temperatures.		Reducing the incidence of uncontained engine failures should be a priority in the strategic safety plan.	
Alternative power sources		Federal agencies should continue to support re-search in nontraditional power concepts and technologies, especially those that support the use of alternative fuels.	Quieter, more environmentally friendly aircraft engines are not only possible, but highly desirable over the near- and longer-term. More distant, but intriguing, are the possibilities for engines using alternative fuels, including hydrogen. A vigorous pursuit of these technologies is likely to pay rich dividends to the United States air transportation system and the national economy.	To reduce conflicts between the growth of aviation and environmental stewardship, NASA, the FAA, and the Environmental Protection Agency (EPA) should augment existing research by developing specific programs aimed at exploring the suitability of alternate sources of energy for application to aviation, taking full account of safety and operational constraints.		Increase public funding for long-term research and RDT&E Infrastructure in breakthrough energy sources. Additional research in this area will be a primary contributor to the goal of reducing transit time and it will also help reduce noise and emissions.		<i>Recommends Against:</i> The committee has concluded that it would be inappropriate to use the limited resources available for development of commercial supersonic aircraft technology to support basic research in alternative power and propulsion systems that show no particular promise for or relevance to supersonic applications.			

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Cockpit displays/ avionics		Further develop, in support of long-term operational concepts, methods for identifying information required for situation awareness and display technologies for supporting situation awareness and decision making (such as synthetic vision, cockpit and controller displays).						In order for industry to take on the development of an economically viable, environmentally acceptable commercial supersonic aircraft, continued advances are necessary in cockpit displays that incorporate enhanced vision systems.		The Commission recommends that the strategic plan for accident reduction contain specific action items to reduce the incidence of controlled flight into terrain; among these action items should be the implementation of requirements for enhanced ground proximity warning systems. In order to prevent runway incursions, NASA and FAA have developed cockpit and ATC displays which present moving map and virtual heads-up presentations of airport taxi-routes and traffic during low visibility. This technology offers great promise for the future. Improved weather detection and display technologies for aircraft and air traffic controllers should be part of a strategic plan for safety improvement.	Enhanced ground proximity warning systems should be installed in all commercial and military passenger aircraft; there is a need for a forward-looking system that can provide better situational awareness and advanced warning to pilots when they are approaching hazardous terrain. The FAA should explore innovative means to accelerate the installation of advanced avionics in general aviation aircraft.
Composite materials		Federal agencies should continue to support research in composite materials with improved qualities.	Composite-structures research is a critical enabling technology for advanced aeronautical development, and should be vigorously supported. In particular, new advances in manufacturing techniques for large-scale composite structures are required to promote the development of a new generation of aeronautical vehicles.					In order for industry to take on the development of an economically viable, environmentally acceptable commercial supersonic aircraft, continued advances are necessary in airframe materials and structures for lower empty weight fractions and long life. Economically viable supersonic commercial aircraft with cruise speed higher than Mach 2 requires additional, significant research and technology development to overcome high temperatures experienced for extended periods of time by airframe materials.			

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Flight control systems and software		Further develop, in support of long-term operational concepts, avionics technologies that will provide transparent communication, navigation and surveillance capabilities and contribute to reduction of separation standards.	Methodologies that facilitate the development of cost-effective, extraordinarily reliable software and systems for safety critical operations should receive the strongest possible support. There is a continuing need for R&D into flight mechanics and control for new, innovative configurations including unpiloted aircraft. Research to minimize if not entirely eliminate the impact of pilot and operator errors on flight safety should be a primary focus. Research into avionics systems and their applications should be aggressively pursued because their use is pervasive and is often critical to the success of advanced aircraft developments.					In order for industry to take on the development of an economically viable, environmentally acceptable commercial supersonic aircraft, continued advances are necessary in flight control systems and operational procedures for noise abatement during takeoff and landing. Augment current research with new, focused efforts (or significant expansion of effort) in techniques for predicting and controlling aero-propulsive servo-elastic and aircraft-pilot servo-elastic (APSE) characteristics. Future research to support improved aerodynamic performance should include techniques to predict and control transition from laminar flow to turbulent flow.			
Nanotechnology		Federal agencies should continue to support research in nanotechnology, to explore long-range potential for enhancing aircraft performance through the development of advanced avionics and high-performance materials.				Increase public funding for long-term research and RDT&E Infrastructure in nanotechnology. Additional research in this area will help meet the goals of reducing noise and emissions, reducing transit time, and reducing fatal accident rate.					
Systems engineering, and design and integration tools		To understand the challenges of designing complex human-integrated systems, research is needed in the following: ◆ Interdisciplinary approaches to design that include user needs from the beginning ◆ System engineering methods for addressing organizational and systemwide issues. Further develop, in support of long-term operational concepts, systems-engineering methods that are capable of conceiving and analyzing systems of the complexity of air transportation and suitable for governing the design, testing and implementation of these systems.	Fundamental advances in information technology should be vigorously pursued to address the increasing complexity of design decisions and the high costs incurred when inappropriate decisions are taken at early stages in system design based upon inadequate information and knowledge.					Augment current research with new, focused efforts (or significant expansion of effort) in automated, high-fidelity multidisciplinary optimization tools and methods for design, integration, analysis and testing of a highly integrated, actively controlled air-frame-propulsion system. NASA should work closely with engine and airframe manufacturers and other industries, agencies, and universities engaged in developing integrated design tools to develop a comprehensive plan for meeting needs.			

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Aging of non-structural components											In cooperation with airlines and manufacturers, the FAA's Aging Aircraft program should be expanded to cover nonstructural systems, since much less is known about the potential effects of age on non-structural components of commercial aircraft. This would include expanding the FAA-DoD-NASA cooperative aging aircraft program.
Applications to specific vehicles			Research and development into Uninhabited Air Vehicles (UAVs) should be given sustained support addressing issues of reliability, maintainability and cost, so that the full potential of these promising aircraft can be realized. Significant new aerodynamics research is required in support of innovative and promising applications ranging from micro UAVs, to Vertical Takeoff and Landing (VTOL) regional transports to Single Stage to Orbit (SSTO) launch vehicles and hypersonic missiles. The Committee believes the U.S. should emphasize the development of the advanced aeronautical technologies required to maintain leadership in (1) subsonic aircraft, (2) high-speed supersonic aircraft, and (3) short-haul aircraft (rotorcraft, general aviation, commuter).				Committee endorses much of the technological research and development contained in the SATS program; these technological capabilities offer the potential to allow more reliable and safe operations during inclement weather at small airports and to improve the accuracy, timeliness, and relevance of information provided to general aviation pilots.	Supersonic transports with overland capability will require 10% improvement in four major factors related to economics: ◆ Lift-to-drag ratio ◆ Air vehicle empty weight fraction ◆ Specific fuel consumption ◆ Thrust-to-weight ratio. Sonic boom is a major barrier to development of supersonic aircraft; augment current research with new, focused efforts (or significant expansion of effort) in airframe configurations to reduce sonic boom intensity.			

Appendix C

Abbreviations

AATT	Advanced Air Transportation Technologies
AOS	Aviation Operations Systems
ARMD	Aeronautics Research Mission Directorate
ASP	Airspace Systems Program
ATM	air traffic management
AvSSP	Aviation Safety and Security Program
DoD	Department of Defense
DOT	Department of Transportation
EAS	Efficient Aircraft Spacing
EASI	Efficient Aerodynamic Shapes and Integration
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FM	Formal Methods
FSD	Flight and System Demonstrations
HALE	High-Altitude, Long-Endurance
HMP	Human Measures and Performance
IAIPT	Interagency Integrated Product Team
IBPD	Integrated Budget and Performance Document
IMM	Intelligent Mission Management
IPSFT	Intelligent Propulsion Systems Foundation Technologies
IPT	integrated product team
ITAS	Integrated Tailored Aerostructures
IVSM	Integrated Vehicle Systems Management
JPDO	Joint Planning and Development Office
LEAP	Low Emissions Alternative Power
MOA	memorandum of agreement
MOU	memorandum of understanding
NAS	National Airspace System

NExTNAS	NASA Exploratory Technologies for the National Airspace System
NRA	NASA Research Announcement
NRC	National Research Council
NSTC	National Science and Technology Council
PAV	Personal Air Vehicle
QAT	Quiet Aircraft Technology
R&D	research and development
R&T	research and technology
RDT&E	research, development, test, and evaluation
REDAC	Research, Engineering, and Development Advisory Committee
ROA	Remotely Operated Aircraft
SATS	Small Aircraft Transportation System
SAU	Strategic Airspace Usage
SBT	Space-Based Technologies
SSA	Supersonic Aircraft
ST	Subsonic Transport
TMA	Traffic Management Advisor
TNAS	Transforming the NAS
TRL	Technology Readiness Level
TSA	Transportation Security Administration
TSWIM	Technology for System-Wide Information Management
UAV	uninhabited air vehicle
UEET	Ultra-Efficient Engine Technology
UNITE	UAV National Industry Team
VAMS	Virtual Airspace Modeling and Simulation
VISTA	Vehicle Integration, Strategy, and Technical Analysis
VSP	Vehicle Systems Program

REPORT DOCUMENTATION PAGE				<i>Form Approved</i> OMB No. 0704-0188	
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1. REPORT DATE (MM-YYYY) 06-2005		2. REPORT TYPE Final		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Pressing Needs in Aeronautics Research				5a. CONTRACT NUMBER NASW-00041 Task Order #00031	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Wingrove III, Earl R Hasan, Shahab Nolte, Lauren				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Logistics Management Institute 2000 Corporate Ridge McLean, VA 22102-7805				8. PERFORMING ORGANIZATION REPORT NUMBER LMI-NS454T1	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) NASA Headquarters 300 E Street, SW Washington, DC 20546-001				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT A- Approved for public release (distribute to DTIC and defense libraries, NTIS, or other appropriate government report databases)					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT A recent National Research Council Report, "Securing the Future of U.S. Air Transportation: A System in Peril," recommends that the U.S. government create a comprehensive, widely accepted long-term vision for the global air transportation system and a coherent set of requirements for all federal agencies with a major stake in the air transportation system. As the nation's leading aeronautics research organization, NASA features prominently in the report, and many of the findings and recommendations directly affect NASA. In addition to this NRC report, other reviews dating back to 1997 have addressed issues relevant to the NASA aeronautics technology program. This report is an independent review of the findings and recommendations contained in 11 recent reports.					
15. SUBJECT TERMS NASA, U.S. air transportation system, aeronautics research					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Unclassified Unlimited	18. NUMBER OF PAGES 135pp	19a. NAME OF RESPONSIBLE PERSON Nancy E. Handy
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED			19b. TELEPHONE NUMBER (include area code) 703-917-7249